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LMSC-A311368-A
30 May 1963

FINAL REPORT
PROGRAM 461 RELIABILITY MATERIALS RESEARCH AND APPLICATION
BEHAVIOR OF SLIP RINGS IN A SPACE ENVIRONMENT

Contract AF 04(647)-787

May 1963

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FOREWORD

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The activity described in this document was performed primarily by the Process Development Group of the LMSC Materials Sciences Laboratory.

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SECTION 1
INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

The space environment presents problems in electrical contact phenomena not encountered under atmospheric conditions. Because LMSC is concerned with the proper functioning of Program 461 hardware under vacuum conditions, a program was initiated in late 1960 to study these conditions. Up to July 1962, this program was concerned mainly with the comparison of operating characteristics of various materials in use at that time for sliding contacts and their potential operating characteristics in vacuum. This emphasis was justified by the urgency for improving the performance of mechanisms which were being designed.

In Program 461, slip rings are used to collect data signals, and any noise generated by the slip rings could tend to obscure these signals. The investigation studied the amount of slip ring noise as a function of material combinations, physical design configurations, vacuum or atmospheric effects on life, sliding speed, and brush pressure. In tests after July 1962, the brush and ring configurations of a Program 461 flight item were also studied.

The following sections of this report describe equipment and conditions used in a simulated space environment and discuss results achieved on slip ring systems tested.

1.2 SUMMARY

In this study of the operating characteristics of sliding electrical contacts in a vacuum it was found that noise contributed to the circuit by the sliding interface can be reduced orders of magnitude by supplying a lubricant to the sliding surfaces.

The lubricant can be supplied by two methods:

- It can be supplied by adding a small percent of MoS_2 in a sintered block of fine silver powder to one of the contacts. A vacuum test using this method exhibited an rms noise level of 20 microvolts after 311 hours, after which the test was terminated.
- It can also be supplied to the sliding interface by a continuous or periodic discharge of a low-vapor-pressure oil in the immediate vicinity of the sliding surface. Example: A continuous supply of oil vapor can be delivered from small blocks of 25 percent porous, sintered nylon, physically attached to the interior of a confining cubical in which sliding is occurring.

  The periodic discharge system in the example above, used in an Aerojet General slip ring assembly, resulted in rms noise levels which were less than 100 microvolts over the entire period of a 5000-hour test.

SECTION 2
EQUIPMENT AND PROCEDURE

2.1 GENERAL CONSIDERATIONS

The basic circuit for measuring slip ring noise is shown in block diagram in Figure 2-1. It consists essentially of the following three elements:

a. A power supply for providing a known, constant current
b. The slip ring, which is equivalent to a varying resistance
c. The noise measuring instrumentation, which shows the voltage drop across the slip ring to brush interface.

When a constant current is passed through the slip ring, voltage drop across the interface fluctuates with time (in response to varying contact resistance) in the manner shown in Figure 2-2. Three quantities that define electrical operating characteristics of the slip ring are the following:

a. Voltage, (E_1), is representative of constant minimum resistance of the brush-ring interface (plus lead wires)
b. Voltage difference, (E_1-E_2), which is a measure of average noise of the slip ring
c. Voltage difference, (E_3-E_1), which is a measure of peak noise of the slip ring.

Minimum resistance of the brush-ring interface (R_1) can be computed from measured voltage (E_1) and current (I). If current (I) is increased, voltage (E_1) increases linearly with it, so that resistance (R_1) is a function of brush pressure, brush and ring configuration, materials, sliding velocity, and atmosphere present. When these conditions are held constant, minimum resistance (R_1) and voltage (E_1) are constant with time:

$$R_1 = \frac{E_1}{I}$$

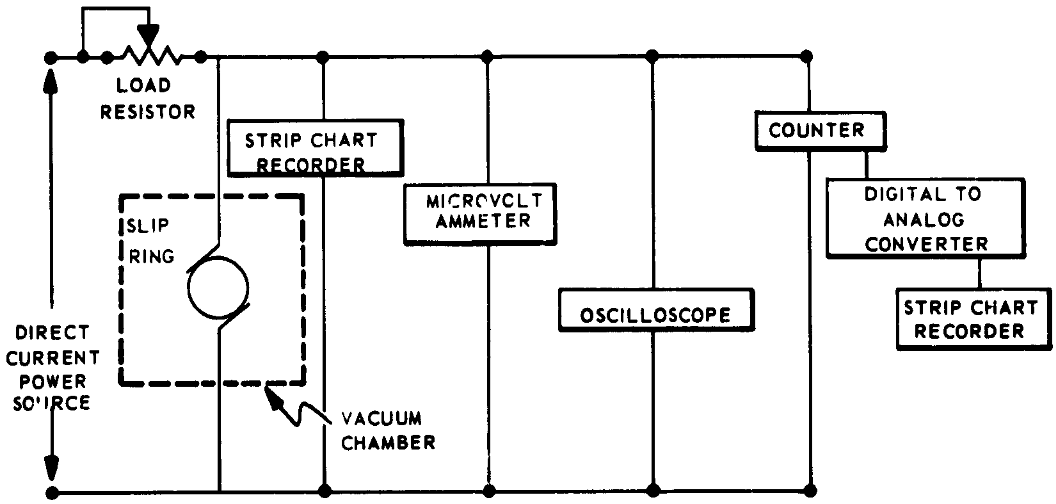

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Figure 2-1 Instrumentation Block Diagram

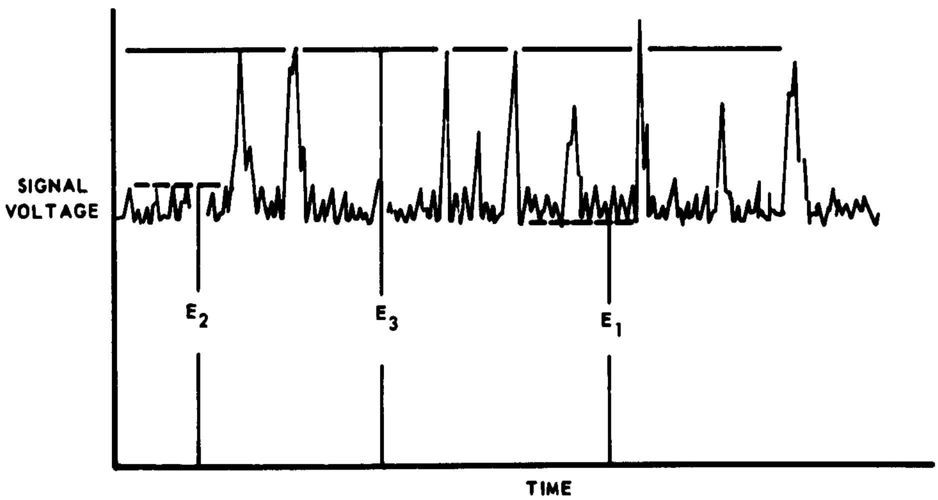

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Figure 2-2 Typical Signal Voltage Versus Time

Average noise and peak noise are conveniently expressed either as millivolts of noise for a specific current, e.g., (E_2-E_1) and (E_3-E_1) at current (I), or as millivolts of noise per microampere of current for a specified current, i.e., $\frac{E_2 - E_1}{I}$ and $\frac{E_3 - E_1}{I}$ at current (I).

Variations of the noise expressions $(E_2 - E_1)$ with current are indicated in Figure 2-3. Note that noise increases with current in a nonlinear manner.

Measurements of noise are affected by the time-response or sensitivity of noise measuring equipment. This is true particularly for peak noise, for which the ability to measure peaks of short (microsecond) duration depends upon the quality of instrumentation. To interpret noise measurements properly and apply them correctly to specific applications requires that sensitivity of the measuring equipment be specified and corresponding needs of the application be known. As can be seen from the above, noise level specifications for equipment must include frequency or time parameters in addition to average or peak voltages.

In all testing described in later sections of this report, signal leads were enclosed in shielded cable for minimum pickup of stray signals from other electrical devices operating in the test area, and shielding was connected to a single ground point to avoid circulating currents or "ground loops" which would have distorted the data.

2.2 POWER SUPPLY

The power supply for these tests includes the following:

a. A source of constant electromotive force (emf) (supplied by Harrison Labs Model 855B and 865B)*

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*The Harrison Lab Models 855B and 865B power supplies were interchanged in tests, depending upon the total current to be delivered to slip rings.

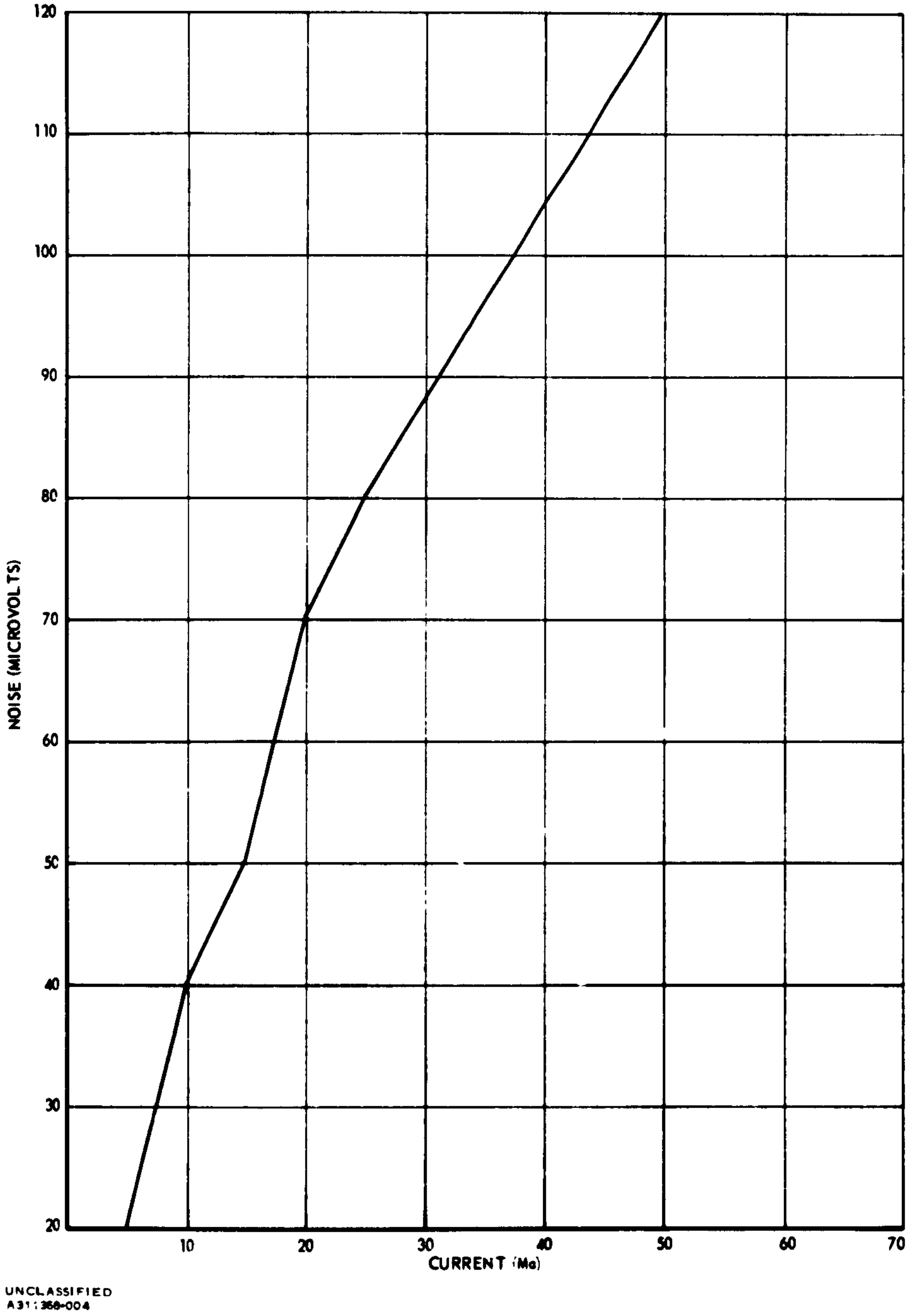

Figure 2-3 Noise Versus Current With Current Varied

b. A high resistance dropping resistor, used to maintain constant current under the small variations in the resistance of the slip ring.

c. A meter for measuring the current delivered to the rings (measured by a Hewlett Packard Model 112-25).

2.3 NOISE MEASURING EQUIPMENT

The following four types of instrumentation were used for measuring voltage drops across the individual slip rings and are shown in Figure 2-4.

a. DC Microvolt-Ammeter, Keithley Model 150 AR

b. Recording potentiometer, Leeds and Northrup Speedomax G, Model No. 69800

c. Oscilloscope, Tektronix Model RM 45A with a type E plug-in preamplifier; low noise amplifier, Keithley Model 103, used for triggering the oscilloscope to observe single noise pulses

d. Digital time and frequency meter, General Radio Model 1130-A, also used with the low-noise amplifier, Keithley Model 103, for triggering the counter to observe single noise pulses

Each of these instruments has an input impedance of one megohm or more.

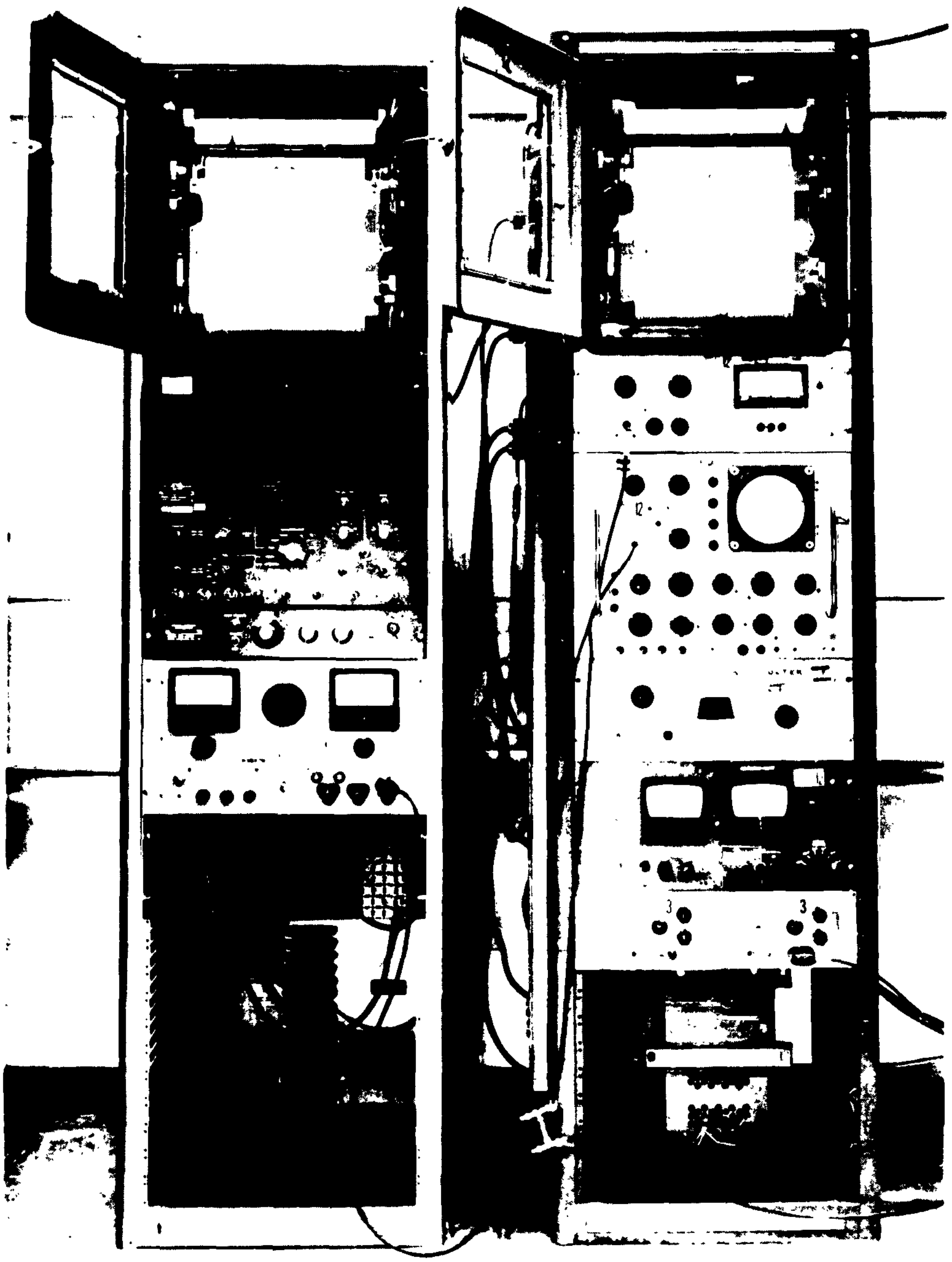

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Figure 2-4 Recording and Noise Measurement Equipment for Tests on Slip Rings

SECTION 3
TEST HARDWARE

3.1 GENERAL DESCRIPTION OF BAIRD-ATOMIC SLIP RING ASSEMBLY (1200 SERIES)

The Baird-Atomic slip ring assembly tested was made up of 240 slip rings (three subassemblies, each with 80 slip rings). The 40 slip rings on each set were concentric, and varied in mean diameter from 3-33/64 (3.52) inches on the innermost ring to 7-49/64 (7.77) inches on the outermost ring. Each ring was 3/64 (0.047) inch wide, and presented a flat surface for the brushes to ride on. The rings were made of fine silver with a gold electroplate between 0.0001 and 0.00005 inch thick on the surface. All rings were separated from adjacent rings by a dielectric 1/16 (0.06) inch wide.

Two brushes were in contact with each slip ring at points diametrically opposite each other. The two brushes rode in approximately the same wear track on each ring, one brush dragging, the other scrubbing (see Fig. 3-1, Example 3. The brushes were made of formed ribbon 0.008 inch thick and 0.020 inch wide. The contact between brush and ring was an elliptical surface with its major axis parallel, and tangent, to the slip ring surface. The brush material was Paliney 7 (a proprietary alloy of palladium, gold, silver, copper, platinum, and zinc by the J. M. Ney Co.), and each brush was fixed to its mounting block. The brushes were held in contact with the slip rings by a three-gram tension supplied by the spring action of the brush material.

3.2 TEST PROCEDURES USED ON BAIRD-ATOMIC SLIP RING ASSEMBLY

Tests were conducted both on an unmodified Baird-Atomic slip ring assembly to determine its potential noise characteristics when operating in vacuum,

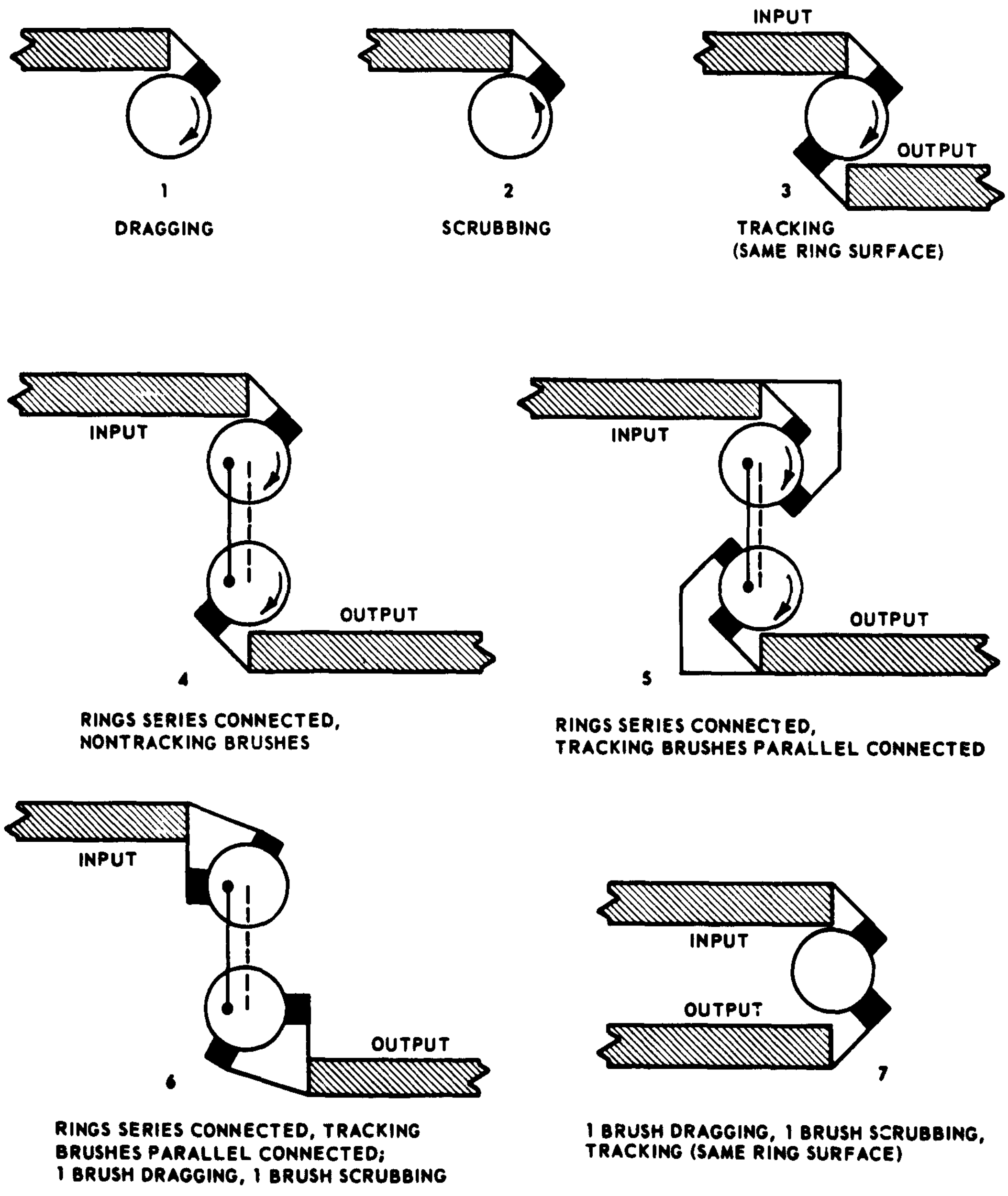

Figure 3-1 Explanation of Contact Attitude

and with one brush modified to see what improvements could be made by chromium plating.

Operating specifications of the Baird-Atomic slip ring assembly were as follows:

a. Rotation. One direction at 6.18 rpm ±10 percent. This results in sliding velocities which range from 5.69 feet per minute on the innermost ring to 12.55 feet per minute on the outermost ring.

b. Current. Fifty milliamps through each signal brush, 750 milliamps through each power brush.

c. Allowable Noise. Five millivolts maximum through a signal brush when carrying 50 milliamps of current (5000/50 = 100 μv/ma).

3.2.1 Test A-1 on Unmodified Assembly. Table 3-1 summarizes the test conditions and noise results obtained from a typical unmodified slip ring and brush from the Baird-Atomic slip ring assembly when operating in vacuum, on equipment shown in Figure 3-2. A record of the data collected is presented in Table 3-2.

A visual inspection of the assembly prior to operation revealed numerous gold flakes that extended into the dielectric on some rings. Numerous scratches were also visible without magnification on the contacting surfaces. Foreign particles were also present on the ring surfaces, and brushes had accumulated a deposit of gold and other debris. It was decided rather than to attempt any cleaning procedure prior to testing, that might introduce false test conditions, the unit would be tested as a representative sample of a production item.

Due in part to the urgency of test results, the slip ring assembly was placed in vacuum operation at a rotational speed of 4.5 rpm. This speed was readily available in the existing laboratory equipment and was not considered to be a significant change from operational speed where measurements of noise were the primary concern.

Table 3-1

TEST A-1 ON UNMODIFIED 1200 SERIES SLIP RING/BRUSH ASSEMBLY FROM BAIRD-ATOMIC SLIP RING ASSEMBLY

<u>Test Conditions</u>

Slip ring material:	Fine silver with 0.0001 to 0.00005 inch gold electroplate (see Fig. 3-6)
Slip ring configuration:	Flat, concentric ring, 3/64 inch wide
Brush material:	Paliney 7 (See Figures 3-3, 3-4, and 3-5 for brush assembly used.)
Brush pressure:	3 grams per brush
Brush configuration:	Ribbon, 0.008 inch thick x 0.020 inch wide
Brush attitude:	1 brush dragging and 1 brush scrubbing, tracking (see Fig. 3-1, example 7)
Rotational speed:	4.5 rpm. (4.2 ft/minute sliding velocity)
Current:	30 milliamps, DC, ring 9. A second brush on ring 7 had no current except when noise measurements were made
Temperature:	Ambient
Vacuum equipment:	Oil diffusion pump with water baffle and liquid nitrogen trap

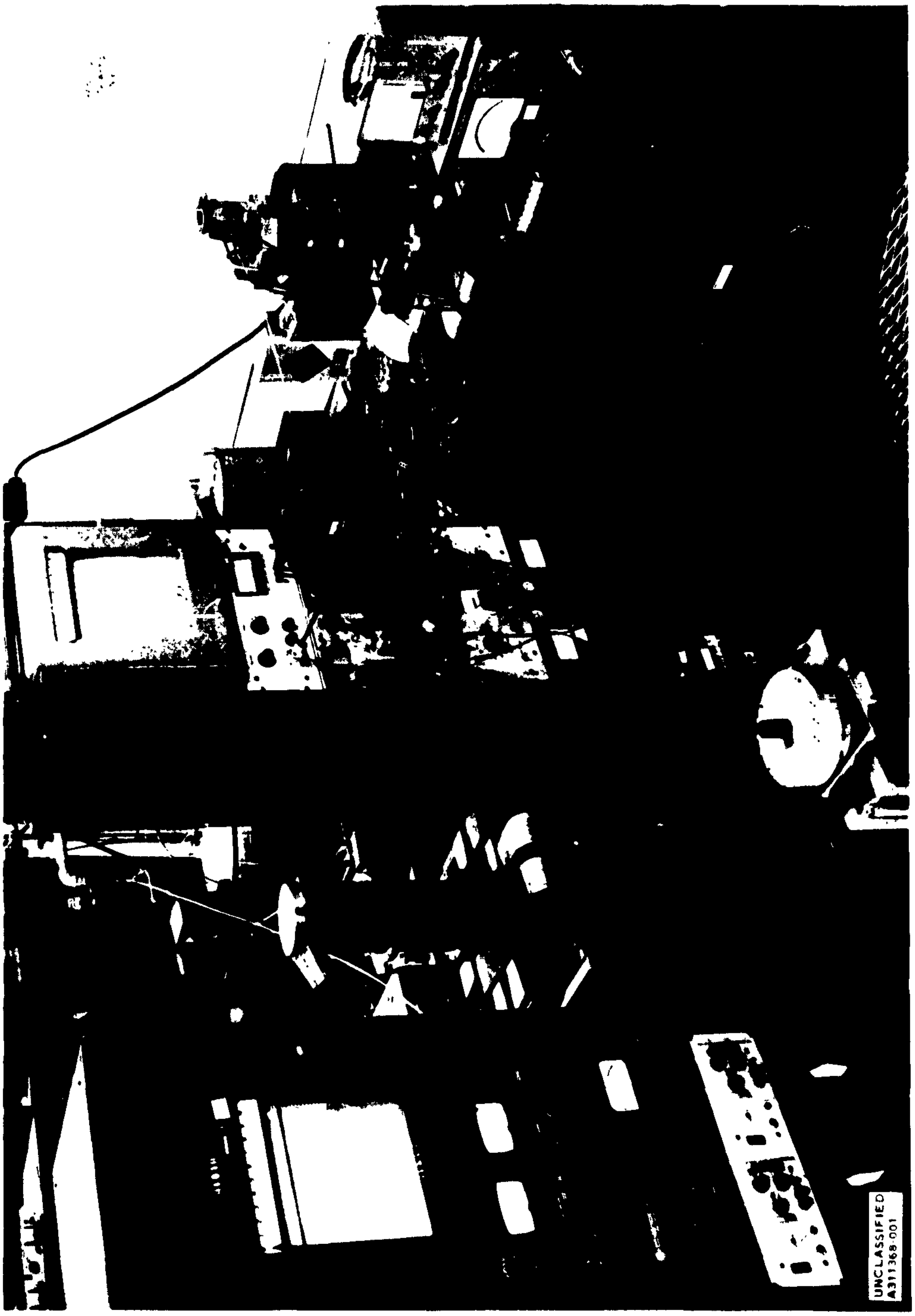

Figure 3-2 Equipment Used for Testing Baird-Atomic and Pacific Scientific Assemblies

Table 3-2

RECORD OF DATA WITH UNMODIFIED BAIRD-ATOMIC ASSEMBLY

Date	Time	Time of Rotation (hr)	Pressure (mm Hg)	Brush/ Ring Set	Current (ma)	Microvolts (Avg)	Microvolts (Peak)	Remarks
7-13-61	1515	0	2×10^{-7}	9	10	150	500	Started rotation
	1630	1.25	1.9×10^{-7}	9	30	300	1,050	
	1800	2.75	2×10^{-7}	9	30	---	---	Closed gate valve Pressure increased; defective seal
7-14-61	1025	19.33	1.5×10^{-1}		30	---	---	Started repumping
7-17-61	1015	24	7×10^{-8}	9	20	---	---	Rotation and current resumed with current at 20 ma
	1615	30	7×10^{-8}	9	20	400	1,175	
7-18-61	900	46.75	7.5×10^{-8}	9	20	400	1,185	
	1100	48.75	7.2×10^{-8}	9	20	425	1,300	
	1400	51.75	5×10^{-8}	9	22	125	300	Current reset at 22 ma
	1700	54.75	1×10^{-7}	9	22	200	450	
7-19-61	1030	72.25	1.4×10^{-7}	9	22	300	1,350	Current reduced to 10 ma
	1040	72.41	1.4×10^{-7}	9	10	150	300	300 milliohm contact resistance
7-20-61	0900	94.75	1.4×10^{-7}	9	10	600	2,100	Current reduced to 1.1 ma
	0915	95.00	1.4×10^{-7}	9	1.1	150	650	Current increased to 5 ma
	0920	95.12	1.4×10^{-7}	9	5	300	1,200	Current reduced to 1.0 ma
	1400	99.75	7×10^{-8}	9	1	50	150	Noise measurements made at varied current levels
					5	100	350	
					10	250	900	
					20	800	3,800	

Table 3-2 (Continued)

Date	Time	Time of Rotation (hr)	Pressure (mm Hg)	Brush/ Ring Set	Current (ma)	Microvolts (Avg)	Microvolts (Peak)	Remarks
7-21-61	0830		2×10^{-6}	9	20	---	---	Trap warmed - diffusion pump oil in system
	0900	118.75	6×10^{-8}	9	5	4,000	8,000	Noise measurements taken and power removed from ring 9 to test ring 7
					1	2,000	9,500	
	0900	118.75	6×10^{-8}	7	1	20	200	Noise measurements taken, ring 7
					5	80	900	
					10	175	2,000	
					20	250	2,600	
					50	---	7,000	
	1400	123.75	6×10^{-8}		5	800	6,000	
	1800	127.75	6×10^{-8}		5	1,400	9,500	
	1805	127.75	6×10^{-8}	9	30	---	---	Power returned to ring 9
7-24-61	0900	190.85	2×10^{-6}	9	30	---	---	Trap warmed over weekend
	1115	193	9×10^{-8}	9	30	150	250	Pressure up Noise measurements taken
	1200	193.75	9×10^{-8}	9	30	150	200	
	1300	194.75	1×10^{-7}	9	30	100	150	
	1415	196	1×10^{-7}	9	30	100	150	
	1515	197	1×10^{-7}	9	30	150	300	
	1540	197.5	1×10^{-7}	9	30	250	800	
	1640	198.5	8×10^{-8}	9	30	200	600	
	1730	100.25	5×10^{-8}	9	30	100	200	

Table 3-2 (Continued)

Date	Time	Time of Rotation (hr)	Pressure (mm Hg)	Brush/ Ring Set	Current (ma)	Microvolts (Avg)	Microvolts (Peak)	Remarks
7-25-61	0900	214.5	7×10^{-8}	9	20	100	150	Noise measurements taken
	1645	222.25	7×10^{-8}	9	10	150	2,300	
7-26-61	1500	244.5	1×10^{-7}	9	20	100	150	Test terminated - equipment failure

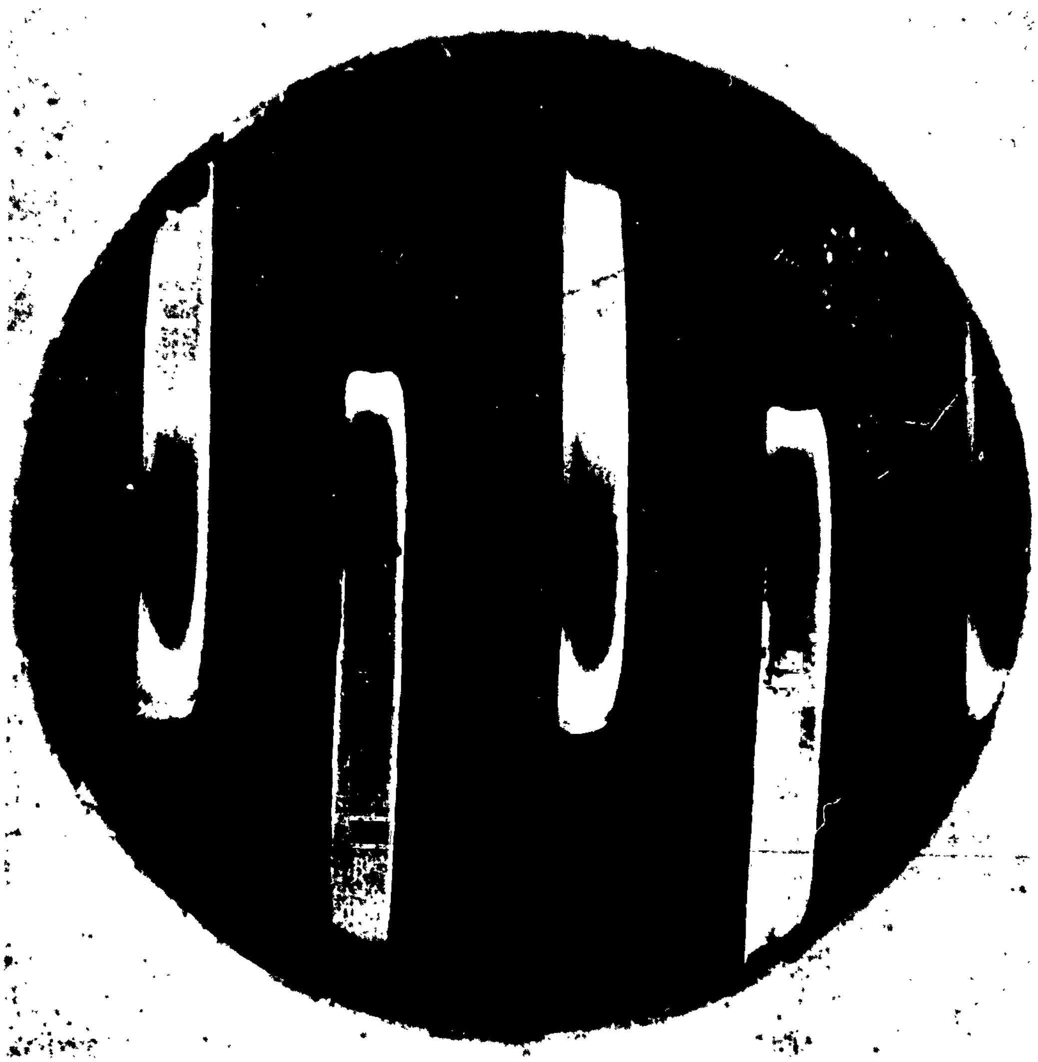

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Figure 3-3 Baird-Atomic Brush Assembly (Unused); Material: Paliney 7, 10% Gold, 30% Silver, 10% Platinum, 35% Palladium, 14% Copper, 1% Zinc

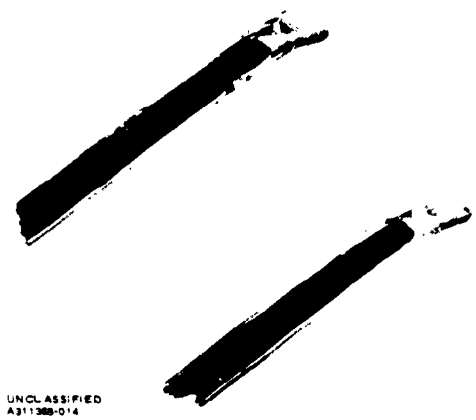

Figure 3-4 Baird-Atomic Brushes After Approximately 30 Hours Wear

Figure 3-5 Baird-Atomic Hard Chromium Plate Brushes After Approximately 30 Hours Wear

Figure 3-6 Baird-Atomic Mod 1 Slip Ring (Unused); Material: Gold Flash, 0.0001 to 0.00005 on Fine Silver

This speed gave sliding velocities of 4.26 feet per minute for the brush ring combination at 3.62 inches mean diameter, selected for no current wear tests (reported as Brushes/Ring Set No. 7 on Table 3-2) and 5.35 feet per minute for the brush/ring combination at 4.54 inches mean diameter (Brush/Ring Set No. 9).

Throughout the 244 hours of testing, current on Brush/Ring Set No. 9 was carrying varied current up to 30 milliamps as shown in Table 3-2. After 118.75 hours of rotation, Brush/Ring Set No. 7 was connected to the power source and measurements made to determine its noise characteristics. This comparative test between Rings 9 and 7 was made to determine whether rings rotated without current in vacuum would exhibit the same noise characteristics as one under load under similar rubbing conditions.

As can be seen from test data (Table 3-2), dated 21 July 1961, lack of current through a sliding interface in vacuum does not in itself reduce noise once the system is required to carry current.

Test data on the unmodified Baird-Atomic slip rings No. 7 and 9 generally revealed that noise was 800 microvolts average, 3800 microvolts peak, with 20 milliamps current flowing after 100 hours operation in vacuum of 1×10^{-7} mm. Hg.

$$\text{Measured noise} \quad \frac{3800\ \text{v}}{20\ \text{ma}} = 190\mu\text{v/ma peak}$$

$$\text{Allowable noise} \quad \frac{5000\ \text{v}}{50\ \text{ma}} = 100\mu\text{v/ms.}$$

Additional characteristics as a function of noise with time are shown on Table 3-2.

3.2.2 Test A-1 Conclusions

Analysis of data shows a trend of reduction of noise in presence of Dow Corning 704 silicone oil. Even with an atmosphere of Dow Corning 704 this assembly's noise level is above specified requirements.

3.2.3 Test B-1 on Modified Baird-Atomic Assembly With Chromium Plated Brushes

Table 3-3 (Test B-1) summarizes the test conditions and results obtained with a chromium plated brush in the Baird-Atomic slip ring assembly. The chromium plating was used in an attempt to reduce basic noise values with materials of different crystal structures and atomic diameters. It was also planned to further explore the lowered noise during trap warmups.

Within 24 hours it could be seen that chromium plating was not the solution to noise reduction, and on both occasions when the liquid nitrogen trap was allowed to warm, pressure rose from 1×10^{-7} mm. Hg to 2.5×10^{-6} mm. Hg and the electrical noise decreased (i.e., between 24 and 41 hours and between 50 and 66 hours). It was also noted that when the system was re-evacuated to 1×10^{-7} mm. Hg, noise again increased, but the rate of increase was slower on the second trap warmup than on the first.

Table 3-3

TEST B-1 ON MODIFIED SLIP RING/BRUSH ASSEMBLY
FROM BAIRD-ATOMIC SLIP RING ASSEMBLY

Modification: Use of chromium plating on brushes

Test Conditions

Slip ring material:	Fine silver with 0.0001 to 0.00005 inch gold electroplate (see Fig. 3-6)
Slip ring configuration:	2 flat, concentric rings, 3/64 inch wide at 4.5-inch mean diameter, series connected
Brush material:	Paliney 7, chromium plated
Brush configuration:	Ribbon, 0.008 inch thick x 0.020 inch wide (approximately 100 circular mils of apparent contact area)
Brush pressure:	3 grams per brush
Brush attitude:	1 brush, dragging, each ring (see Fig. 3-1, Example 4)
Rotational speed:	4.5 rpm (5.2 ft./minute sliding velocity)
Current:	0.05 milliamp per brush, DC, continuous during test
Temperature:	Ambient
Vacuum equipment:	Oil diffusion pump with water baffle and liquid nitrogen trap

SUMMARIZED RESULTS OF TEST B-1 ON RINGS 8 AND 6

Rotating Time (hr)	Chamber Pressure (mm. Hg)	Noise Level (Microvolts)		Remarks
		Avg	Peak	
16	1.5×10^{-7}	300	4,100	
24	8×10^{-8}	2,500	14,000	
41	2.5×10^{-6}	2,100	7,200	Liquid nitrogen trap allowed to warm
50	1.5×10^{-7}	2,800	17,000	
66	2.4×10^{-6}	600	1,800	Liquid nitrogen trap allowed to warm
75	2×10^{-7}	700	1,900	
96	1×10^{-7}	800	2,600	

3.2.4 Test B-1 Conclusions

The operation of a hard-faced chromium brush against a silver ring under the conditions described is not successful for reducing noise in hard vacuum. The addition of a partial pressure (10^{-6} Torr) of Dow Corning 704 silicone oil will, however, reduce contact noise even when these materials are used; also, replenishment of this oil vapor reduces the rate of noise rise as time in the partial vacuum is accumulated.

3.3 TESTS ON PACIFIC SCIENTIFIC SLIP RING ASSEMBLIES

Over the time span of this investigation six experimental tests have been performed on the Pacific Scientific slip ring assemblies to evaluate the performance of different material combinations in vacuum. Five tests were successful in accumulating data, but one had to be scrapped because of mechanical difficulties in installation which resulted in displacement of the brushes and caused them to ride on the dielectric, thereby invalidating the results.

3.3.1 Test C-1 on Pacific Scientific Slip Ring Assembly

This test was performed to determine the operating noise characteristics in vacuum of a brush/ring material combination of 80 percent silver and 20 percent graphite working against silver. Rings and brushes used are shown in Figures 3-7 and 3-8, and test conditions are described in Table 3-4. A typical assembly is shown in Figure 3-9.

3.3.1.1 Test C-1 Conclusions. This test indicated that brush mixtures of 80 percent silver and 20 percent graphite worked against silver produce more noise during operation in vacuum (5×10^{-7} mm. Hg) than in air. It also shows that noise will drastically increase using these material combinations after less than two days of operation in vacuum. During both the initial run-in in air, and operation in air following operation in vacuum, the noise level decreased with increased time of operation in air.

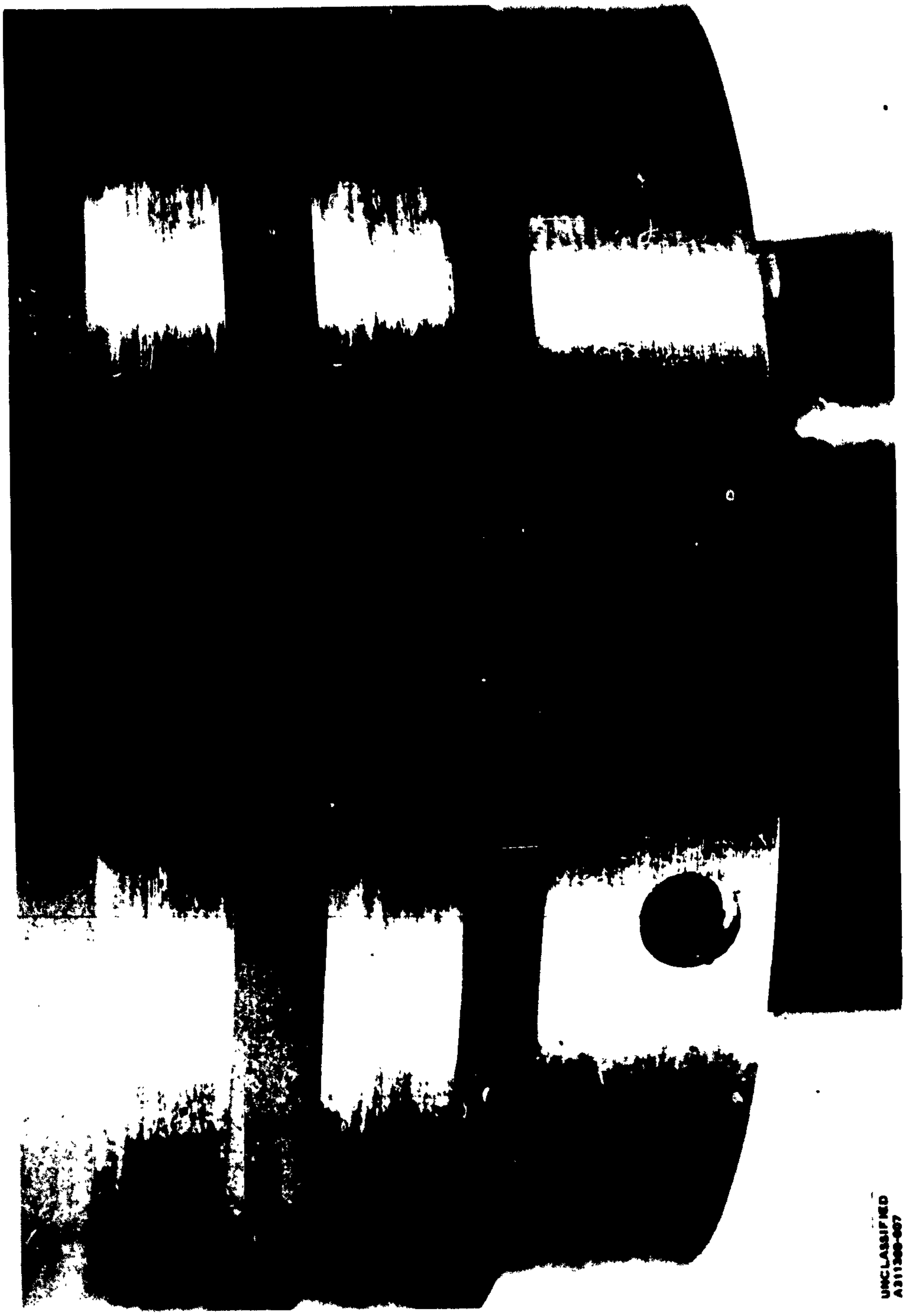

Figure 3-7 Rings Used in Pacific Scientific Test C-1

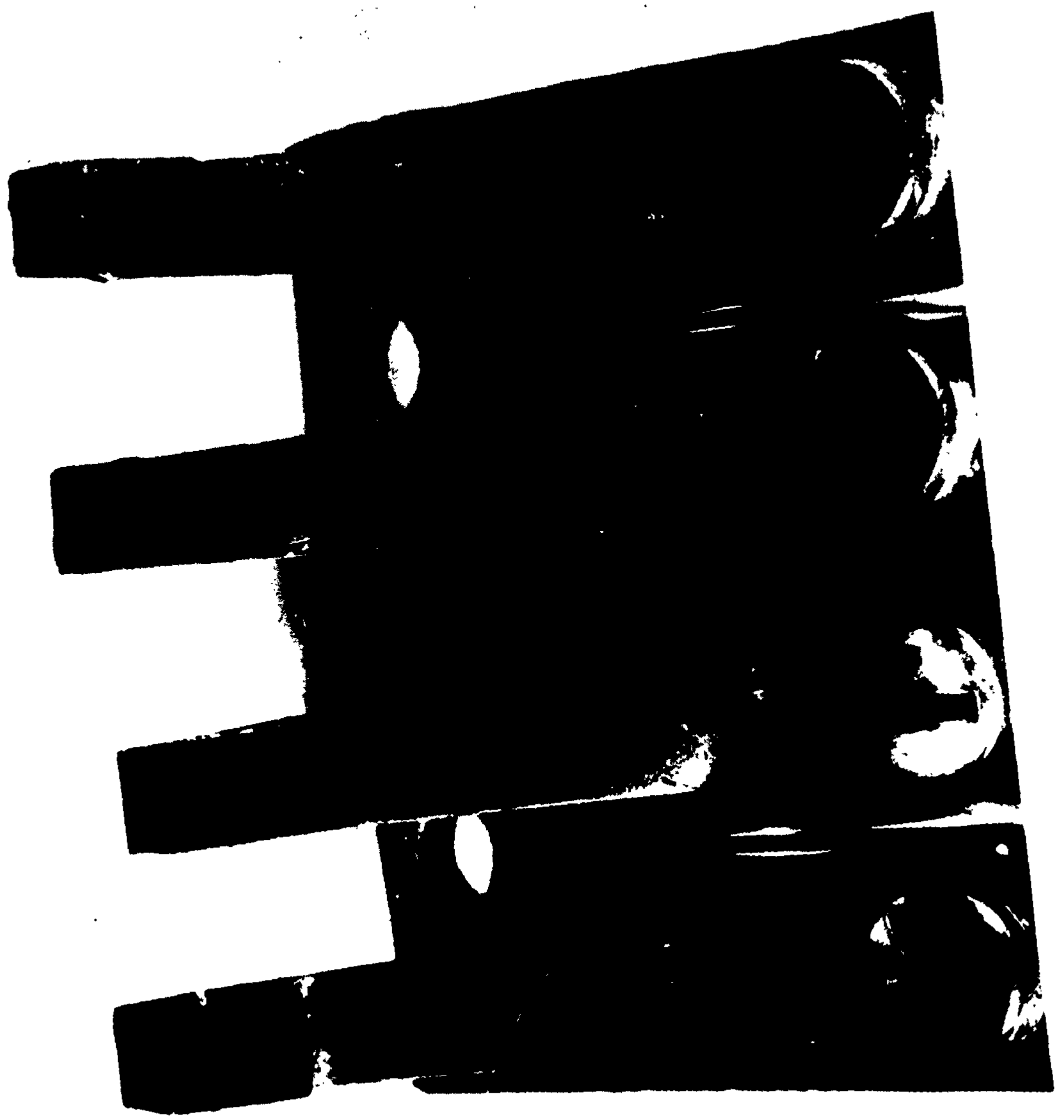

Figure 3-8 Brushes Used in Pacific Scientific Test C-1

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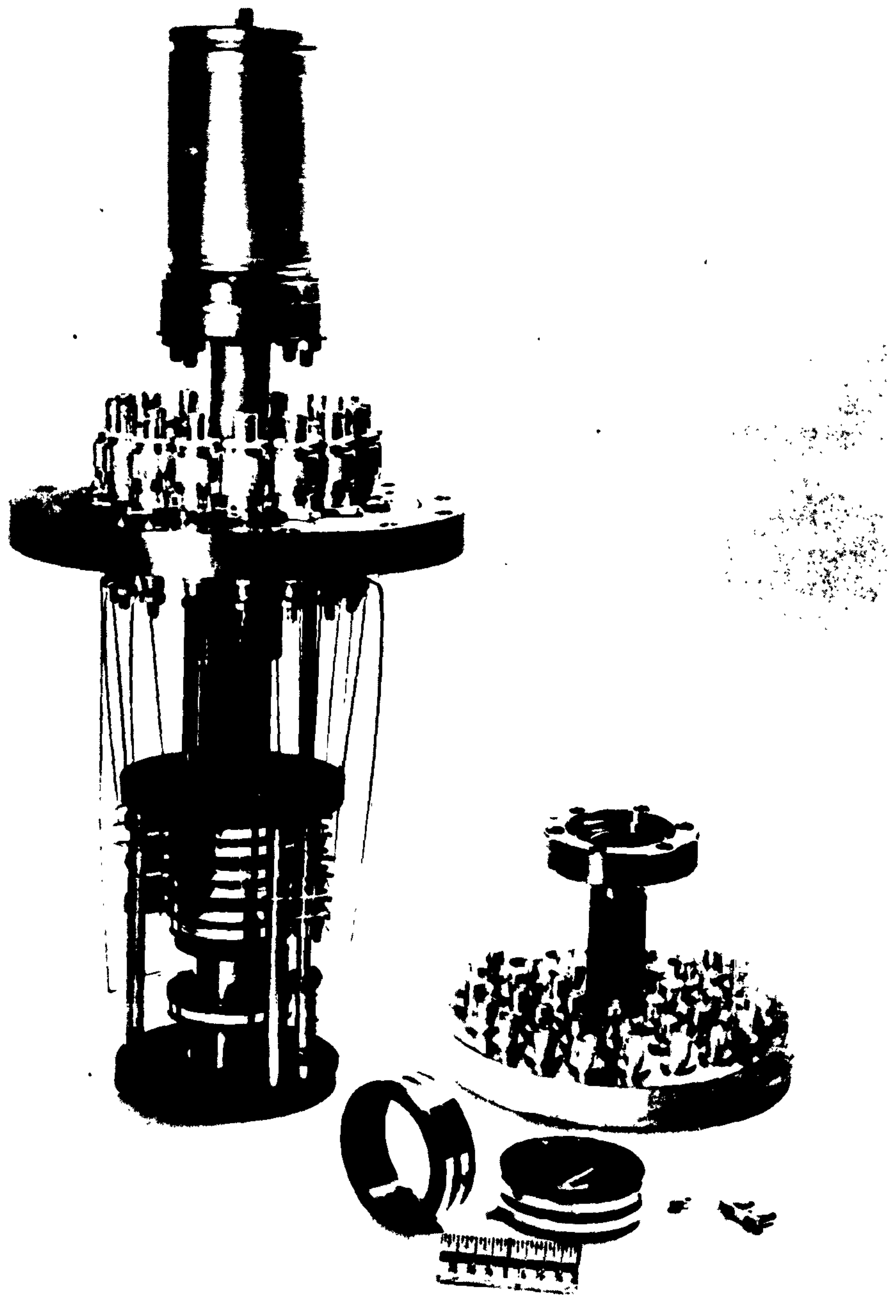

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Figure 3-9 Typical Slip Ring Assembly

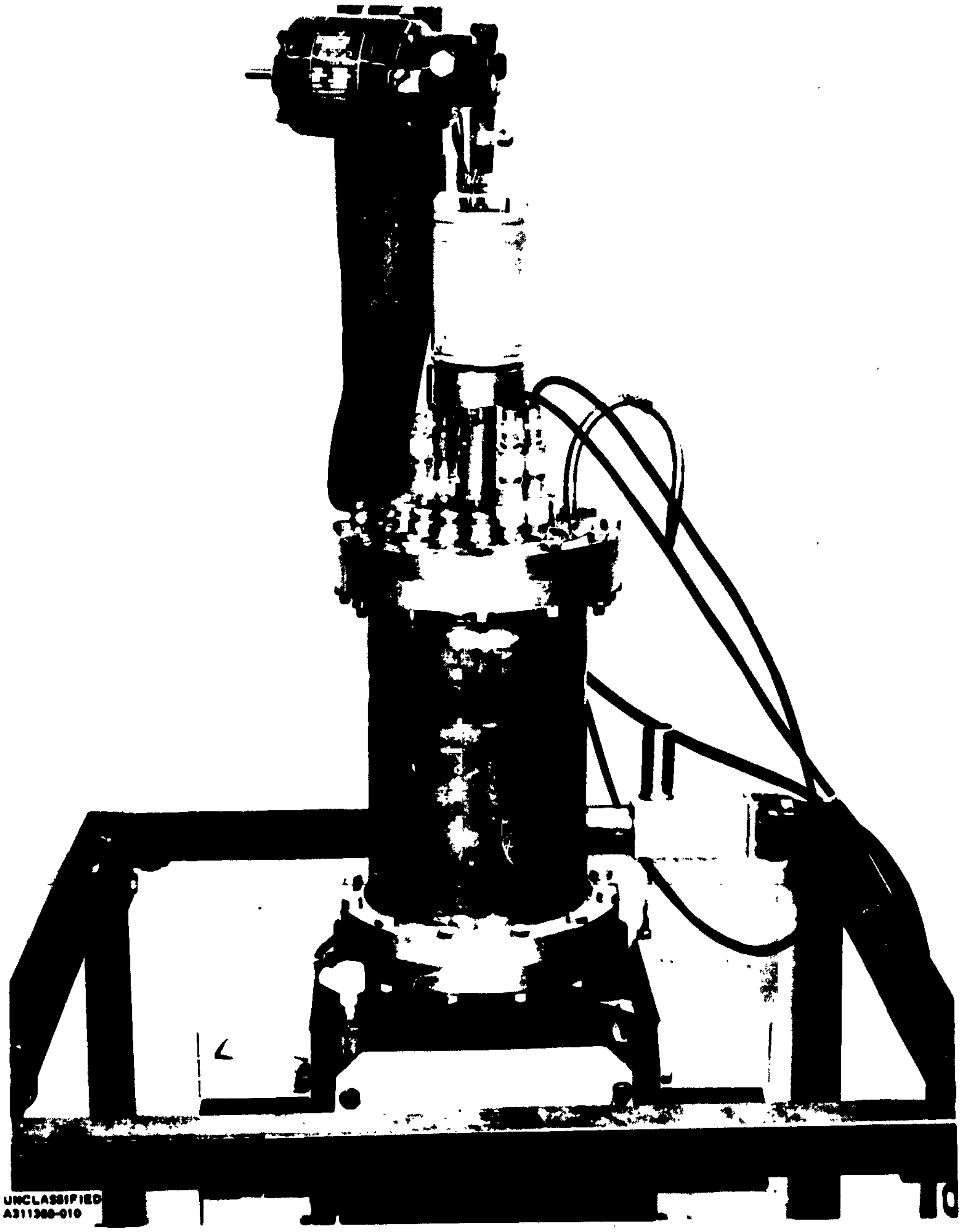


Figure 3-10 Typical Vac Ion System

Table 3-4

TEST C-1 ON PACIFIC SCIENTIFIC SLIP RING ASSEMBLY

Test Conditions

Slip ring material:	Fine silver
Slip ring configuration:	Flat cylincrical surface approximately 8-microinch finish, 2.250 inch diameter x 0.1875 inch wide
Brush material:	80% silver, 20% graphite
Brush configuration:	Buttons, 0.125 inch x 0.186 inch (apparent contact area of 29,600 circular mils)
Brush pressure:	100 grams per brush
Brush attitude:	1 brush dragging on each ring (see Fig. 3-1, Examples 1 and 4)
Rotational speed:	1.81 rpm (1.07 feet/minute on ring periphery)
Current:	200 milliamps per brush
Temperature:	Ambient
Vacuum equipment:	90 liter/sec ion pump (see Fig. 3-10)

SUMMARIZED RESULTS OF TEST C-1
ON PACIFIC SCIENTIFIC ASSEMBLY

Rotating Time (hr)	Chamber Pressure (mm. Hg)	Noise Level (Microvolts)		Remarks
		Avg	Peak	
0	760	230	--	Initial value of noise
1.5	760	150	--	Decrease in noise suspected to be due to run-in in air which allowed brushes to seat properly
5.5	760	40	--	Evacuation begun
23.5	10^{-7}	400	2000	Increase in noise due to first 18 hours of operation in vacuum
26.5	10^{-7}	600	2600	
29.5	10^{-7}	700	2800	

Table 3-4 (Continued)

52.5	10^{-7}	1100	to 6500	System let to air
65.5	760	500	2500	Decrease in noise after 13 hours operation in air

3.3.2 Test C-2 on Pacific Scientific Slip Ring Assembly

This test was a continuation of material combination investigation. Table 3-5 summarizes the test conditions of the seven combinations of brush and ring materials used. Results of these tests are shown in Table 3-6. Rings used are shown in Figure 3-11.

Table 3-5

TEST C-2 ON PACIFIC SCIENTIFIC SLIP RING ASSEMBLY

Test Conditions

Material:

Brush	Ring
88% silver/12% moly disulphide	Rhenium plated silver
80% silver/20% graphite	Rhodium plated silver
88% silver/12% moly disulphide	Rhodium plated silver
80% silver/20% graphite	Electrodeposited copper
88% silver/12% moly disulphide	Electrodeposited copper
80% silver/20% graphite	Electrodeposited silver
88% silver/12% moly disulphide	Electrodeposited silver

Slip ring configuration:	Flat cylindrical surface approximately 8 microinch finish, 2.25 inch diameter x 0.1875 inch wide
Brush configuration:	Buttons, 0.116 inch x 0.184 inch (average)
Brush pressure:	103 grams average (variable from 100 to 109 grams per brush)
Brush attitude:	1 brush dragging, 1 brush scrubbing, tracking (see Fig. 3-1, Example 7)

Table 3-5 (Continued)

Rotational speed:	17.8 rpm (10.5 feet/minute sliding velocity)
Current:	32 milliamperes per brush
Temperature:	Ambient
Vacuum equipment:	90-liter/sec ion pump (see Fig. 3-10)

3.3.3 Test C-3 on Pacific Scientific Slip Ring Assembly

Table 3-7 summarizes the test conditions and results obtained as a continuation of Test C-2 using six other material combinations of brush and ring materials. A data record of testing is presented in Table 3-8.

In addition to the normal noise measurements made on this test, each brush was weighed prior to testing to evaluate wear qualities of moly disulphide and graphite mixtures when used against ring materials shown in Table 3-7.

Table 3-6
LOGGED RESULTS OF TEST C-2

	Brush	88% Silver/12% Moly Disulphide		80% Silver 20% Graphite		88% Silver/12% Moly Disulphide		80% Silver/ 20% Graphite		88% /12% Moly Disulphide		80% Silver/ 20% Graphite		88% Silver/12% Moly Disulphide	
	Ring	Rh Plated Silver		Rh Plated Silver		Rh Plated Silver		Copper		Copper		Silver		Silver	
	Time	Peak µv	Avg µv	Peak µv	Avg µv	Peak µv	Avg µv	Peak µv	Avg µv	Peak µv	Avg µv	Peak µv	Avg µv	Peak µv	Avg µv
(Hours in Air)	0	5000	1000	80	40	10	10	5000	10000	4000	700	30	10	200	50
	2	8000	400	80	30	20	10	30000	10000	1500	500	40	20	200	30
	4	8000	300	20	10	20	10	21000	8000	2000	600	50	20	150	50
	6	7000	300	20	10	30	20	14000		1500	700	30	10	400	30
	22	300	200	10	10	100	50	600	300	800	300	30	10	300	80
(Hours in Vacuum)	0	100	20	100	20	50	20	80	20	100	50	150	50	75	20
	6	30	10	150	75	20	10	700	300	50	10	250	150	100	50
	30	175	75	275	150	10	10	250	150	50	10	200	100	10	10
	52	250	150	400	200	15	10	250	150	75	20	1100	500	80	10
	60	275	150	600	300	20	10	500	200	400	200	100	20	50	20
	130	500	300	500	250	20	10	500	300	75	20	75	20	10	10
	158	900	400	300	200	20	10	1100	500	200	75	150	50	20	10
	178	600	400	700	500	14	10	1200	600	700	100	2800	400	20	10
	202	550	200	6500	2500	25	10	700	400	125	25	8000	1500	20	10
	226	700	300	10500	5000	31	10	800	400	125	50	11500	2000	25	10

NOTES: All noise figures shown taken at 32 milliamps of current flowing at a vacuum of low 10^{-6} mm. Hg

Peak noise - Largest shown on Leeds-Northrop recorder.

Average noise - Oscillation of recorder pen.

10 millivolts full scale
1 second full scale

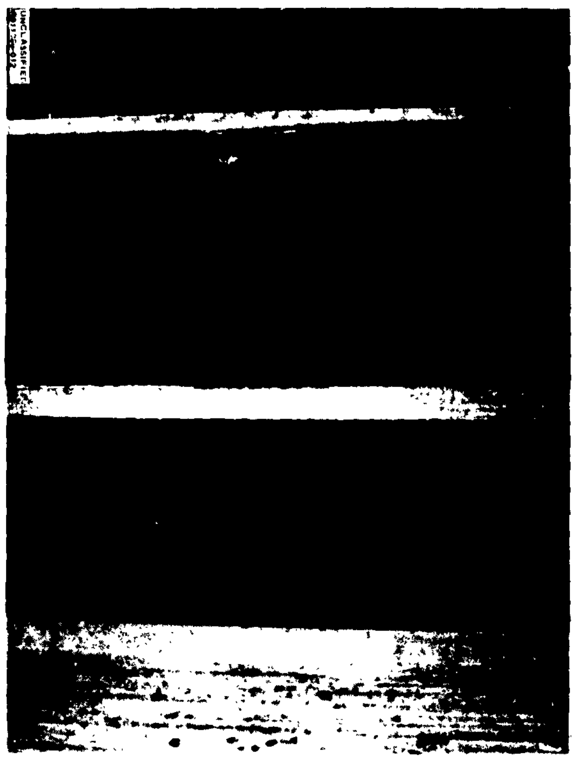


Figure 3-11 Silver Rings Used in Pacific Scientific Test C-2

Table 3-7

TEST C-3 ON PACIFIC SCIENTIFIC SLIP RING ASSEMBLY

Test Conditions

Material:

Brush	Ring
80% silver/20% graphite	Electrodeposited gold
88% silver/12% moly disulphide	Electrodeposited gold
80% silver/20% graphite	Electrodeposited palladium
88% silver/12% moly disulphide	Electrodeposited palladium
80% silver/20% graphite	Electrodeposited rhenium
88% silver/12% moly disulphide	Electrodeposited chromium

Slip ring configuration:	Flat cylindrical surface approximately 8 microinch finish of fine silver, 2.25-inch diameter x 0.1875 inch wide.
Brush configuration:	Buttons, 0.116 inch x 0.184 inch
Brush pressure:	100 grams average
Brush attitude:	1 brush dragging, 1 brush scrubbing, tracking (see Fig. 3-1, Example 7)
Rotational speed:	17.8 rpm (10.5 feet/minute sliding velocity)
Current:	25 milliamps, dc continuous through each brush
Temperature:	Ambient
Vacuum equipment:	90-liter/sec ion pump (2×10^{-7} mm. Hg average)

SUMMARIZED RESULTS OF TEST C-3 ON PACIFIC SCIENTIFIC ASSEMBLY

Ring Material	Brush Material	Final Results After 311 Hours in Vacuum: Noise Level (in microvolts) Avg	Peak	Brush Weight Loss %
Gold	88% silver/12% moly disulphide	20	50	0.025
Gold	80% silver/20% graphite	100	300	2.9
Rhenium	80% silver/20% graphite	300	550	0.1
Palladium	88% silver/12% moly disulphide	20	80	0.035
Palladium	80% silver/20% graphite	1800	6300	2.3
Chromium	88% silver/12% moly disulphide	450	7500	0.2

Table 3-8
LOGGED RESULTS OF TEST C-3

Brush Ring Time	88% Ag, 12% MoS_2 Au Plated Ag		80% Ag, 20% Graphite Au Plated Ag		80% Silver, 20% Graphite Re Plated Ag		88% Silver, 12% MoS_2 Pa Plated Ag		80% Silver, 20% Graphite Pa Plated Ag		88% Silver, 12% MoS_2 Cr Plated Ag	
	Peak μv	Avg. μv	Peak μv	Avg. μv	Peak μv	Avg. μv	Peak μv	Avg. μv	Peak μv	Avg. μv	Peak μv	Avg. μv
0	3.4 k	180	10.5 k		3200	220	7.8 k		6.5 k		5 k	
24	1500	200	3.3 k	400	150	20	3.2 k	700	2.5 k	300	18 k	
33	300	150	6 k		50	20	600	300	1100	550	6.6	700
59	220	150	15 k	400	2.9 k	350	600	160	50	20	7 + k	1.3 k
73	150	50	3.2 k	600	8 + k		1.7 k	650	75	50	7 + k	1.5 k
97	450	150	1.2 k	550	8 + k		1.2 k	550	50	30	6 + k	1.2 k
112	275	150	550	220	8.5 + k		1.2 k	350	160	50	4.4 k	750
136			1.8 k	650	6.5 k	1.2 k	1.1 k	350			10 + k	1.4 k
142	75	8	7.7 k	2.5 k	1.9 k	400	1 k	250	300	27	7.8 k	
168	110	28	850	350	75	12	300	200	1.2 k	400	8.3 k	900
											(System pressure increased to tens of mm. of Hg overnight (Seal Failure)	
176	50	20	475	300	90	30	850	100	5 k	2.3 k	7 + k	1.4 k
188	50	20	850	500	120	40	90	20	4 k	1.3 k	1.3 k	350
204	100	20	500	150	90	30	100	50	6 k	1 k	950	350
229	100	50	65	30	100	65	210	90	2.8 k	350	7.3 k	400
311	50	20	300	100	550	300	80	20	6.3 k	1.8 k	7.5 k	450

NOTE: All noise figures shown taken at 5 milliamps of current flow.

3.3.4 Test C-4 on Pacific Scientific Slip Ring Assembly

Test C-4 had to be scrapped because of mechanical difficulties before any useful data were obtained. Misalignment of contacting surfaces caused the brushes to ride on the dielectric separators, contaminating them beyond further use.

3.3.5 Test C-5 on Pacific Scientific Slip Ring Assembly

The test conditions and results of Test C-5 are given in Tables 3-9 and 3-10.

Table 3-9

TEST C-5 ON PACIFIC SCIENTIFIC SLIP RING ASSEMBLY

Test Conditions

Slip ring material:	Electrodeposited silver
Slip ring configuration:	Two flat cylindrical surfaces, series connected, 2.25 inch diameter x 0.187 inch wide. Finish, approximately 8 microinches
Brush material:	Paliney 7
Brush configuration:	Wire, 0.007-inch diameter. Two connected in parallel contacting each ring, tracking (see Fig. 3-1, Example 5)
Brush pressure:	3 to 3.1 grams
Brush attitude:	Dragging
Rotational speed:	4.75 rpm (2.8 feet/minute sliding velocity)
Current:	As noted in Table 3-10
Temperature:	Ambient
Vacuum equipment:	90-liter/sec ion pump

Table 3-8
LOGGED RESULTS OF TEST C-3

Brush Ring Time	88% Ag, 12% MoS_2 Au Plated Ag Peak µv	88% Ag, 12% MoS_2 Au Plated Ag Avg. µv	80% Ag, 20% Graphite Au Plated Ag Peak µv	80% Ag, 20% Graphite Au Plated Ag Avg. µv	80% Silver, 20% Graphite Re Plated Ag Peak µv	80% Silver, 20% Graphite Re Plated Ag Avg. µv	88% Silver, 12% MoS_2 Pa Plated Ag Peak µv	88% Silver, 12% MoS_2 Pa Plated Ag Avg. µv	80% Silver, 20% Graphite Pa Plated Ag Peak µv	80% Silver, 20% Graphite Pa Plated Ag Avg. µv	88% Silver, 12% MoS_2 Cr Plated Ag Peak µv	88% Silver, 12% MoS_2 Cr Plated Ag Avg. µv
0	3.4 k	180	10.5 k		3200	220	7.8 k		6.5 k		5 k	
24	1500	200	3.3 k	400	150	20	3.2 k	700	2.5 k	300	18 k	
33	300	150	6 k		50	20	600	300	1100	550	6.6	700
59	220	150	15 k	400	2.9 k	350	600	160	50	20	7 + k	1.3 k
73	150	50	3.2 k	600	8 + k		1.7 k	650	75	50	7 + k	1.5 k
97	450	150	1.2 k	550	8 + k		1.2 k	550	50	30	6 + k	1.2 k
112	275	150	550	220	8.5 + k		1.2 k	350	160	50	4.4 k	750
136			1.8 k	650	6.5 k	1.2 k	1.1 k	350			10 + k	1.4 k
142	75	8	7.7 k	2.5 k	1.9 k	400	1 k	250	300	27	7.8 k	
168	110	28	850	350	75	12	300	200	1.2 k	400	8.3 k	900
											(System pressure increased to tens of mm. of Hg overnight (Seal Failure)	
176	50	20	475	300	90	30	850	100	5 k	2.3 k	7 + k	1.4 k
188	50	20	850	500	120	40	90	20	4 k	1.3 k	1.3 k	350
204	100	20	500	150	90	30	100	50	6 k	1 k	950	350
229	100	50	65	30	100	65	210	90	2.8 k	350	7.3 k	400
311	50	20	300	100	550	300	80	20	6.3 k	1.8 k	7.5 k	450

NOTE: All noise figures shown taken at 5 milliamps of current flow.

3.3.4 Test C-4 on Pacific Scientific Slip Ring Assembly

Test C-4 had to be scrapped because of mechanical difficulties before any useful data were obtained. Misalignment of contacting surfaces caused the brushes to ride on the dielectric separators, contaminating them beyond further use.

3.3.5 Test C-5 on Pacific Scientific Slip Ring Assembly

The test conditions and results of Test C-5 are given in Tables 3-9 and 3-10.

Table 3-9

TEST C-5 ON PACIFIC SCIENTIFIC SLIP RING ASSEMBLY

Test Conditions

Slip ring material:	Electrodeposited silver
Slip ring configuration:	Two flat cylindrical surfaces, series connected, 2.25 inch diameter x 0.187 inch wide. Finish, approximately 8 microinches
Brush material:	Paliney 7
Brush configuration:	Wire, 0.007-inch diameter. Two connected in parallel contacting each ring, tracking (see Fig. 3-1, Example 5)
Brush pressure:	3 to 3.1 grams
Brush attitude:	Dragging
Rotational speed:	4.75 rpm (2.8 feet/minute sliding velocity)
Current:	As noted in Table 3-10
Temperature:	Ambient
Vacuum equipment:	90-liter/sec ion pump

Table 3-10

LOGGED RESULTS OF TEST C-5

Date	Time	Rotated Time (hr)	Comment
1-26-62	1340	3	History to this time: 1 hr operation in air 1 hr operation in rough vacuum 1 hr operation in fine vacuum
1-26-62	2030	9.5	Lifetime in vacuum, 6.8 hr Drop varied from 5 mv at 5 ma to source voltage (0 current)
1-26-62	2035	9.6	Started 50 ma test current through contacts (vacuum 1×10^{-6})
1-29-62	0900	70	Noise 70 μv at 5 ma current (vacuum 1×10^{-6}). Returned test current to 50 ma
1-30-62	1330	99.7	Noise 40 μv at 5 ma (vacuum 1×10^{-6})
1-30-62	1845	105	Noise 25 μv at 5 ma (vacuum 1×10^{-6})
1-31-62	0900	119.25	Noise 110 μv at 5 ma (vacuum 1×10^{-6})
2-1-62	0900	143.25	Voltage drop check at varied current 24 ma 10.1 mv 20 ma 8.3 mv 15 ma 6.2 mv 10 ma 4.1 mv 5 ma 2.1 mv (vacuum 7×10^{-7})

Table 3-10 (Continued)

Date	Time	Rotated Time (hr)	Comment
2-1-62	1100	145.25	Check to determine if noise level was linear with current Current (ma) — RMS Noise (μv) 5 — 20 10 — 40 15 — 50 20 — 70 25 — 80 50 — 120
2-1-62	1700	151.25	Recheck of noise linearity Current (ma) — RMS Noise (μv) 50 — 140 5 — 25
2-2-62	0900	167.00	Test terminated. Lost vacuum due to rotary seal failure on on equipment.

3.3.6 Test C-6 on Pacific Scientific Slip Ring Assembly

Test C-6 test materials and conditions are described in Table 3-11.

Table 3-11

TEST C-6 ON PACIFIC SCIENTIFIC SLIP RING ASSEMBLY

Test Conditions	
Slip ring materials:	88% silver/12% moly disulphide
Slip ring configuration:	Flat cylindrical surface, 2.25-inch diameter x 0.187 inch-width
Brush materials:	80% silver/20% graphite, 2 on ring 1, tracking (see Fig. 3-1, Example 7) 88% silver/12% moly disulphide, 2 on ring 2, tracking (see Fig. 3-1, Example 7)
Brush configuration:	Buttons, 0.116 inch x 0.184 inch
Brush pressure:	100 grams
Brush attitude:	One brush dragging, one brush scrubbing
Rotational speed:	6 rpm
Current:	20 milliamperes
Temperature:	Ambient
Vacuum equipment:	360-liter/sec ion pump
Vacuum:	3×10^{-8} mm. Hg

3.3.7 Conclusions From Tests C-1, C-2, C-3, C-5, and C-6

The following conclusions were obtained from Tests C-1, C-2, C-3, C-5, and C-6:

a. If a partial pressure (10^{-6} Torr) of oil vapor such as Dow Corning 704 silicone oil is maintained in the cubicle of a slip ring's sliding action, the noise level will, in general, be no greater after 300 hours in vacuum than its atmospheric noise level.

b. At the different surface speeds investigated in Tests C-1 and C-2, no significant noise increase or decrease is shown that can be attributed to surface speed alone. Data do, however, show a trend toward increasing noise with higher surface speeds when current differences of Tables 3-4 and 3-6, Column 6, are considered.

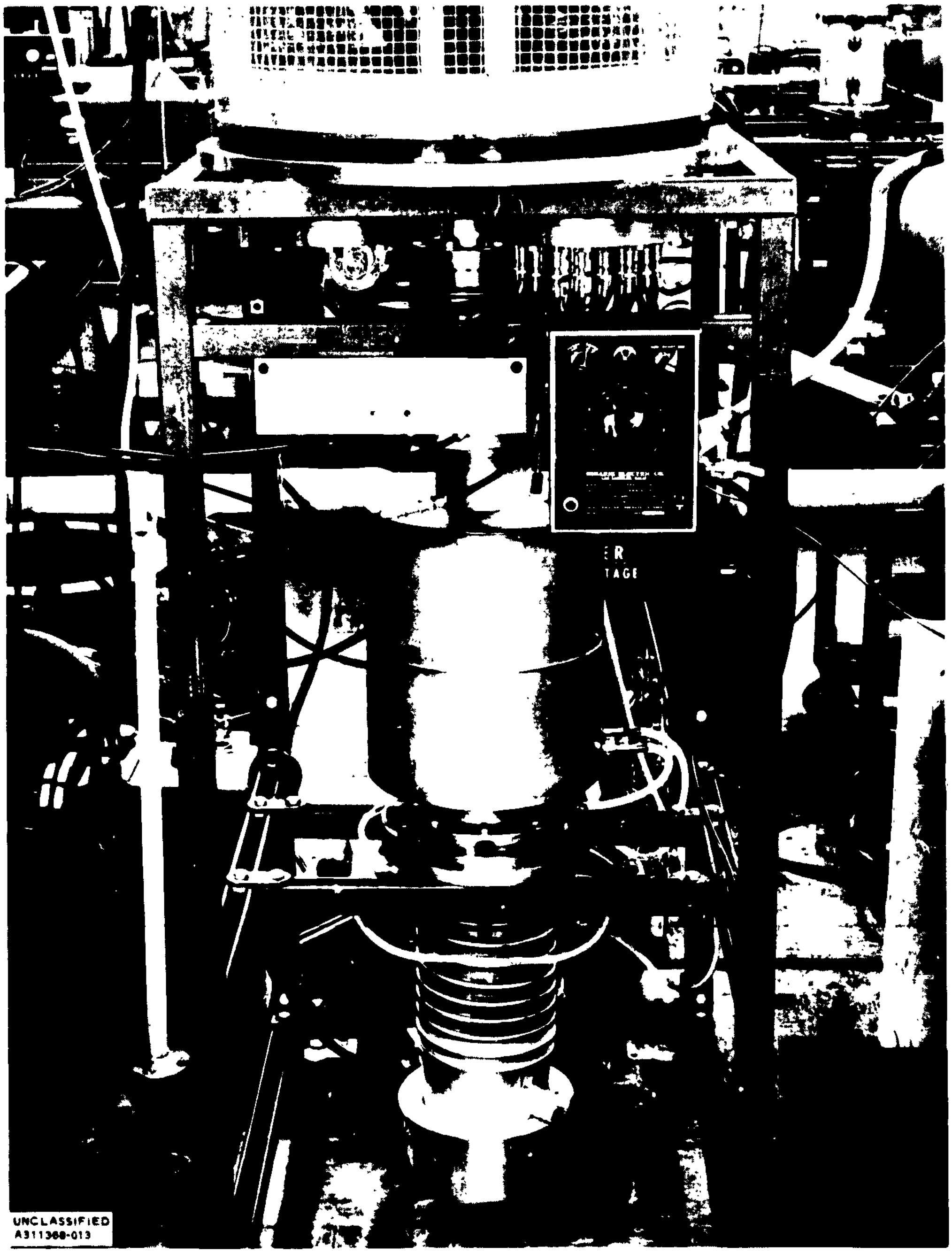


Figure 3-12 Typical Diffusion Pumping Station

c. Chromium plated surfaces do not exhibit as low an inherent noise characteristic as precious metal types when used against solid-type lubricants (MoS_2 and silver) or partial oil atmosphere types (Dow Corning 704). (See Tables 3-2, 3-3, and 3-7.)

d. Molybdenum disulphide is an effective lubricant for systems of this type even without assistance from a partial atmosphere of Dow Corning 704, particularly if wear particles will create no problem on or in adjacent equipment.

3.4 TEST D-1 ON POLY-SCIENTIFIC SLIP RING ASSEMBLY

The first tests with a Poly-Scientific slip ring assembly were in progress at time of termination of testing activity. The D-1 graphs in Appendix A show measured RMS noise at a noise test current of 5 milliamps. Vacuum equipment is shown in Figure 3-12 and test materials and conditions are described in Table 3-12.

Table 3-12

TEST D-1 ON POLY-SCIENTIFIC SLIP RING ASSEMBLY

Test Conditions

Material:

Test Ring No.	Brush	Ring
1	93% silver/7% graphite	Coin gold
2	Paliney 7	Coin gold
3	93% silver/7% graphite	Electroformed gold, 0.010 inch on silver
4	93% silver/7% graphite	Electroformed gold, 0.002 inch on silver
5	Paliney 7	Electroformed gold, 0.010 inch on coin gold (annealed)
6	Paliney 7	Coin silver (annealed)
7	Paliney 7	Electroformed silver

Table 3-12 (Continued)

Slip ring configuration:	Flat cylindrical surface, 2.25-inch diameter x 1.87 inch wide, approx. 8-microinch surface finish
Brush materials:	Silver/graphite, 3/32 inch x 5/32 inch, two on same ring, tracking (see Fig. 3-1, Example 3) Paliney 7, 1/16 inch x 1/8 inch, two on same ring, tracking (see Fig. 3-1, Example 3)
Brush attitude:	Dragging
Brush pressure:	10 grams
Rotational speed:	17.8 rpm (10.5 feet/minute sliding velocity)
Current:	20 milliamps
Temperature:	Ambient
Vacuum equipment:	Welch 1402, Veeco 300 liters/sec, Lockheed cold trap

3.4.1 Test D-1 Conclusions

Although the basic noise level of noble metal contacts would be normally lower than those containing percentages of graphite under vacuum usage, contacts containing graphite can be operated for greater than 6500 hours in space vacuum conditions when operated in a cubicle that will maintain a continuous low pressure atmosphere of Dow Corning 704 oil.

3.5 TEST E-1 AEROJET-GENERAL ASSEMBLY (1200 SERIES)

On 15 June 1962, the first Aerojet-General Corporation slip ring assembly was delivered to LMSC Palo Alto laboratories for testing. The slip ring assembly was manufactured by Slip Ring Corporation of America. Upon receipt, the assembly was examined under 45-diameter magnification. This examination revealed that approximately 75 percent of the rings appeared to be contaminated with at least one particle of debris per ring.

Because of the urgent need for performance information on this assembly under vacuum operation, and the fact that it could be considered as a typical flight assembly, no attempt was made to perform analyses of the debris material. However, attempts were made to remove this debris by the application of a strippable collodion to 10 of the rings for comparative testing.

Selection of the 17 rings for test (the limit of the vacuum chamber electrical feed-throughs) was made in a random manner, with each ring having two unused rings between its internally series-connected input and output rings.

Brushes of six ring combinations were modified by removing a scrubbing or dragging contact (see Fig. 3-1, Examples 1 and 2). This was done to compare noise levels that might result with single brushes. Nine brush/ring combinations were tested in the as-received condition, and two of the collodion-cleaned rings were also tested. These combinations are identified in Table 3-13, test conditions are given in Table 3-14, and RMS noise test results when carrying a 5 milliamp current are given in Appendix A on Test E-1 graphs.

In this assembly each brush is a 0.007-inch-diameter wire made of Paliney 7 alloy with a pressure of three grams against the coin silver slip rings. Because of the previous test histories of these materials in other LMSC tests and their low noise performance under partial pressure of Dow Corning 704, six blocks of 25 percent porous sintered nylon, which had been vacuum impregnated with an average weight of 0.3 gram of Dow Corning 704 silicone oil, were attached to the inside of the slip ring confining cubicle prior to testing.

3.5.1 Test E-1 Conclusions

Excluding contamination by debris, which can considerably influence the noise characteristics in use, and contamination dislodged by environmental factors of launch vibration and shock, if a partial pressure of oil vapor such as described in this test procedure is used on this assembly, the RMS noise level for a given rotary movement and a given number of rings, will be no greater than its preflight performance after 5000 hours of space exposure.

Table 3-13

BRUSH/RING COMBINATIONS TESTED

Test Number	Special Conditions	Normal Rotating Current (ma)
1	Single contact, dragging	50
2	Single contact, dragging	50
3	Single contact, scrubbing	50
4	Single contact, scrubbing	50
5	Cleaned contacts	50
6	Cleaned contacts	50
7	Single contact, dragging	50
8	Single contact, dragging	50
9	As received	100
10	As received	750
11	As received	1
12	As received	1
13	As received	10
14	As received	10
15	As received	50
16	As received	50
17	As received	100

Table 3-14

TEST E-1 ON AEROJET-GENERAL ASSEMBLY

Test Conditions

Slip ring material:	Coin silver
Slip ring configuration:	90-degree V-grooved, 0.015 inch wide and 2.312 inches in diameter, approximately 16-microinch finish
Brush material:	Paliney 7
Brush configuration:	Wire, 0.007-inch diameter. See Table 3-13.
Brush pressure:	3 grams
Brush attitude:	See Table 3-13
Rotational speed:	6 rpm
Current:	See Table 3-13
Temperature:	Ambient
Vacuum equipment:	Diffusion pump with Lockheed cold trap (vacuum reached was 1×10^{6} mm. Hg) See Figure 3-12

3.6 RADIOACTIVE TRACER STUDY OF CONTACT SURFACE WEAR MADE AT HAZELTON NUCLEAR SCIENCE CORPORATION

The following paragraphs are a digest of the final report submitted by Hazelton-Nuclear Science Corporation covering work done on subcontract C25-45818-T + M.

3.6.1 Summary

The radioactivity tracer study for determining ring and brush wear has been successfully completed. A set of two neutron-irradiated Ag-MoS_2 brushes was run for 111.7 hours at three revolutions per 58 seconds with a set of two nonirradiated Ag rings. Measurements of specific activities of Ag^{110m} and Mo^{99} from each brush, as compared with an irradiated but not run brush, showed a total wear of silver from the brushes of 354 ±70 and 164 ±32 micrograms and of MoS_2 of 14 ±6 and 11.5 ±5.5 micrograms. Transfers to the rings were, respectively, 278 ±28 and 88 ±9 micrograms for silver and 5.6 ±2.2 and 3.7 ±2.1 micrograms for MoS_2. This test showed a greater than anticipated total wear of the brushes and a fractionation of the two components of the Ag-MoS_2 brushes during wear on Ag rings. From the experience gained, it is anticipated that in any future tests the probable errors can be reduced significantly.

3.6.2 Introduction

On 5 April 1962, a set of three Ag-MoS_2 brushes was irradiated for neutron activation in the General Electric Test Reactor at Vallecitos and, after a suitable decay period and arrangements with LMSC, two of these were installed with a set of two nonirradiated Ag rings in the test apparatus at the Lockheed Research Laboratory under health physics supervision on 13 April 1962.

After a run of 111.7 hours at three revolutions per 58 seconds, the test chamber was taken to the Hazelton Nuclear Science Corporation radiochemistry laboratories on 18 April, and dismantled for radiochemical analysis.

3.6.3 Calculation

During disassembly of the test chamber, the following samples were carefully taken.

Designation	Description
B_u	The reference unused brush
B_3	Brush No. 3
B_4	Brush No. 4
R_3	Ring No. 3
R_4	Ring No. 4
L_3	Loose materials on brush No. 3
L_4	Loose materials on brush No. 4
L_R	Loose materials on both rings (collected together by necessity)
L_a	Loose material in the test chamber

The weight of Ag or Mo transferred to the rings was calculated from the equation:

$$\text{Wt transferred } (\mu\text{ g}) = \frac{\text{total activity in ring (cpm)} \times 1000}{\text{specific activity in brush (cpm/mg)}}$$

The weight of Ag or Mo in the loose materials was calculated from the equation:

$$\text{Wt transferred } (\mu\text{ g}) = \frac{\text{total activity in material (cpm)} \times 1000}{\text{specific activity in brush (cpm/mg)}}$$

The radioactivity so calculated for the loose materials on the rings and in the test chamber is the sum of the wear from both brushes. For the total wear calculations, it was arbitrarily assumed the wear was equal from both brushes.

For the total wear of the brushes, the following equation was used:

$$W_B \text{ lost } (\mu\text{ g}) = \frac{A_R + A_{LB} + 1/2\,(A_{LR} + L_a) \times 1000}{D_B}$$

The data for this test are given in Tables 3-15 and 3-16.

3.6.4 Conclusions

The data for Ag^{110m}, which are considered reliable, show that a significant amount (278 and 88 μ g) of brush silver transferred to the rings during the 111.7 hours of test operation. Although less reliable, the data for Mo^{99} show that the MoS_2 did not transfer in a proportional manner.

The data also show that more than half of the silver in the wear materials of the brushes transferred to the ring rather than to loose wear particles.

$\left(\frac{278}{352} = 79\% \text{ and } \frac{88}{164} = 54\%\right)$ for silver, while less than half of the MoS_2 transferred to the rings $\left(\frac{5.6}{14} = 40\% \text{ and } \frac{3.7}{11.5} = 25\%\right)$

It is felt that this first radioactivity tracer study for determining wear has been successful, in that an estimate of the extent of silver and MoS_2 transfer has been achieved. This study shows a greater than anticipated total wear, and a fractionation of the two composite materials of the brushes during wear on Ag rings.

It is suggested that with the experience gained during this first test, an identical test would further confirm these observations, and that the probable errors of the data can be reduced significantly.

Table 3-15
Ag^{110m} WEAR DATA

Brushes

No.	Net Counting Rate (cpm)	Dilution Factor	Total Counting Rate (cpm)	Wt (mg) AgCl	Wt (mg) Ag	Specific Activity D (cpm/mg)
B_3	36,600	500	1.83×10^7	143.8	108.0	1.69×10^5
B_4	21,880	500	1.09×10^7	88.5	66.5	1.64×10^5
B_u	26,620	500	1.33×10^7	109.4	82.3	1.62×10^5

Rings

No.	Net Counting Rate (cpm)	Chemical Yield Factor	Total Counting Rate (cpm)	Weight Brush Ag Transferred (μg)
R_3	38,980	0.831	4.70×10^4	278
R_4	11,920	0.831	1.44×10^4	88

Loose Materials

L_3	78	0.790	99	0.6
L_4	1,420	0.734	1.93×10^3	11.4
L_R	3,600	0.867	4.1×10^3	25.3
L_a	15,400	0.932	1.65×10^4	100

Wear of Brushes

$$W_{B_3} \text{ (lost)} = \frac{4.70 \times 10^4 + 99 + 1/2(2.06) \times 10^4}{1.62 \times 10^2} = 354 \ \mu g$$

$$W_{B_4} \text{ (lost)} = \frac{1.44 \times 10^4 + 0.19 \times 10^4 + 1.03 \times 10^4}{1.62 \times 10^2} = 164 \ \mu g$$

Table 3-16

Mo^{99} WEAR DATA

Brushes

No.	Net Counting Rate (4/30/62)	Wt (mg)* $PbMoO_4$	Wt (mg) MoS_2	Specific Activity D (4/30/62) (cpm/mg MoS_2)
B_3	5.45×10^4	12.4	5.4	1.0×10^4
B_4	6.70×10^4	5.2	2.3	2.9×10^4
B_u	7.85×10^4	25.2	10.9	0.72×10^4
Average value used:*				$(1.6 \pm 0.9) \times 10^4$

Rings

No.	Net Counting Rate (4/30/62)	Chemical Yield Factor	Total Counting Rate (4/30/62)	Weight Brush MoS_2 Transferred (μg)
R_3	26 ± 10	0.290	90 ± 35	5.6 ± 2.2
R_4	18 ± 10	0.305	59 ± 33	3.7 ± 2.1

Loose Materials

L_3	<5	0.172	<29	<1.8
L_4	<5	0.304	<17	<1.0
L_R	18 ± 10	0.281	64 ± 35	4.0 ± 2.2
L_a	30 ± 10	0.176	170 ± 57	10.6 ± 3.6

Wear of Brushes

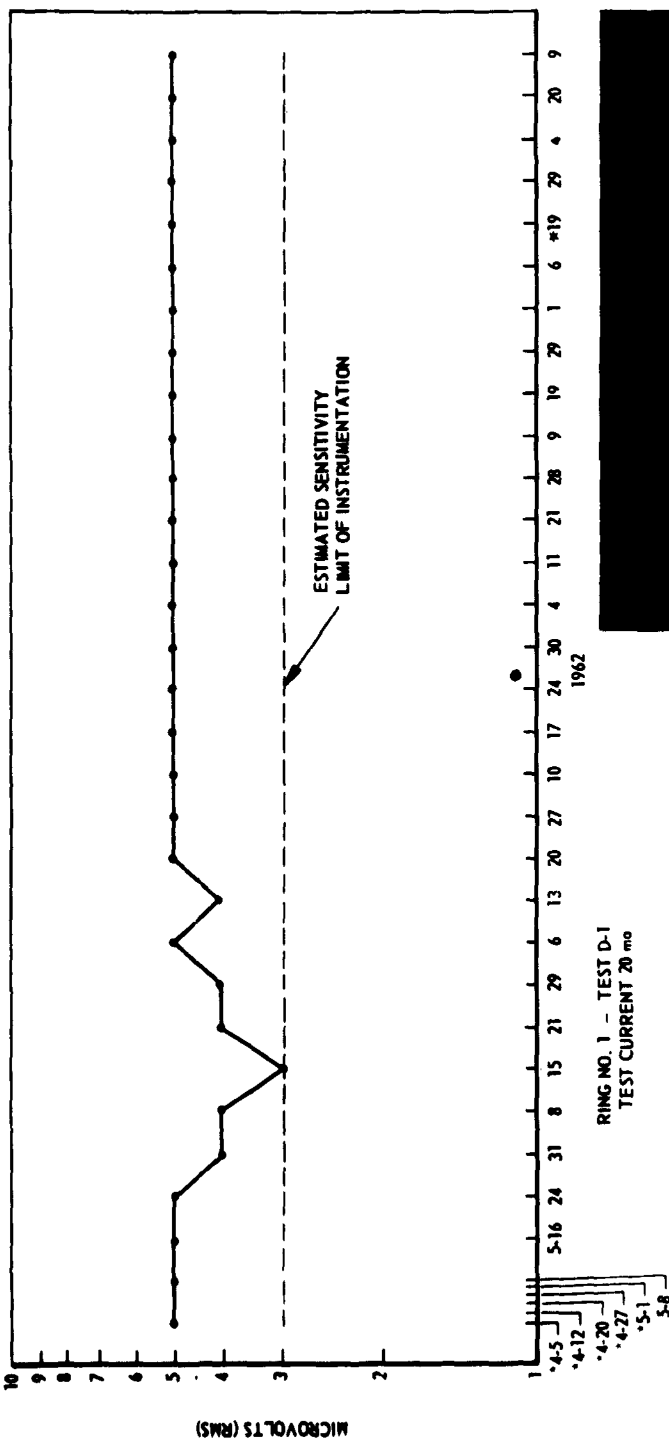
$$W_{B_3} \text{ (MoS}_2\text{ lost)} = \frac{(90 \pm 35) + (15 \pm 15) + (117 \pm 46)}{16} \simeq 14 \pm 6\ \mu g$$

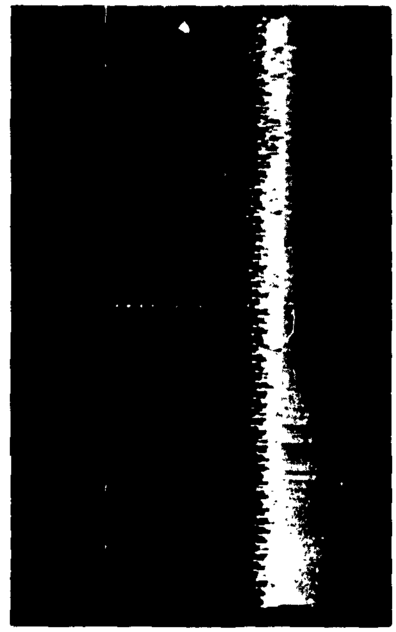
$$W_{B_3} \text{ (MoS}_2\text{ lost)} = \frac{(59 \pm 33) + (9 \pm 9) + (117 \pm 46)}{16} \simeq 11.5 \pm 5.5\ \mu g$$

* **Weight of $PbMoO_4$ may be overestimated if $PbCl_2$ or $Pb(OH)_2$ coprecipitated. Average value used for wear calculations.**

APPENDIX A

GRAPHS

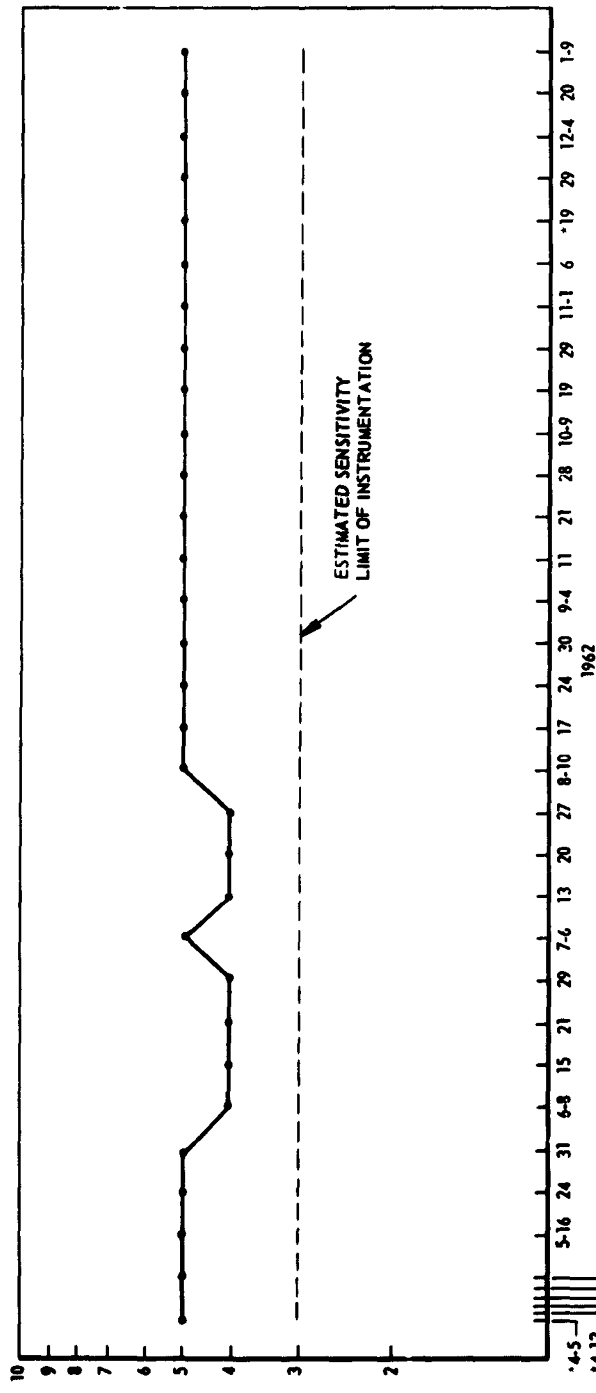




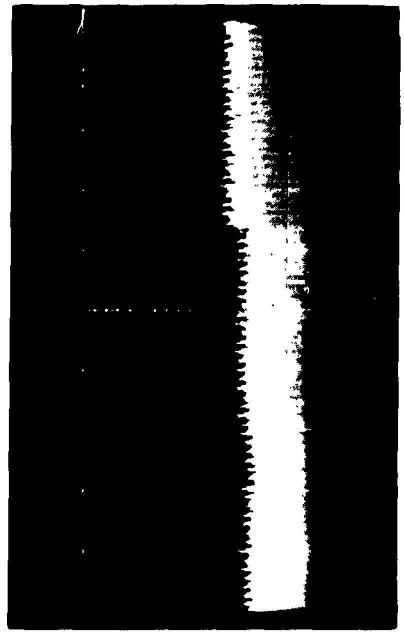
Test current (during this photo): 20 ma
Horizontal sweep speed: 2 cm/sec
Vertical sensitivity: 1 mv/cm
Total test hours: 8500

* BACK DIFFUSION OF OIL TO CHAMBER OCCURRED; CHAMBER SATURATED WITH DOW CORNING 704 OIL VAPOR

UNCLASSIFIED
A311368-A-025



RING NO. 2 – TEST D-1
TEST CURRENT: 20 ma

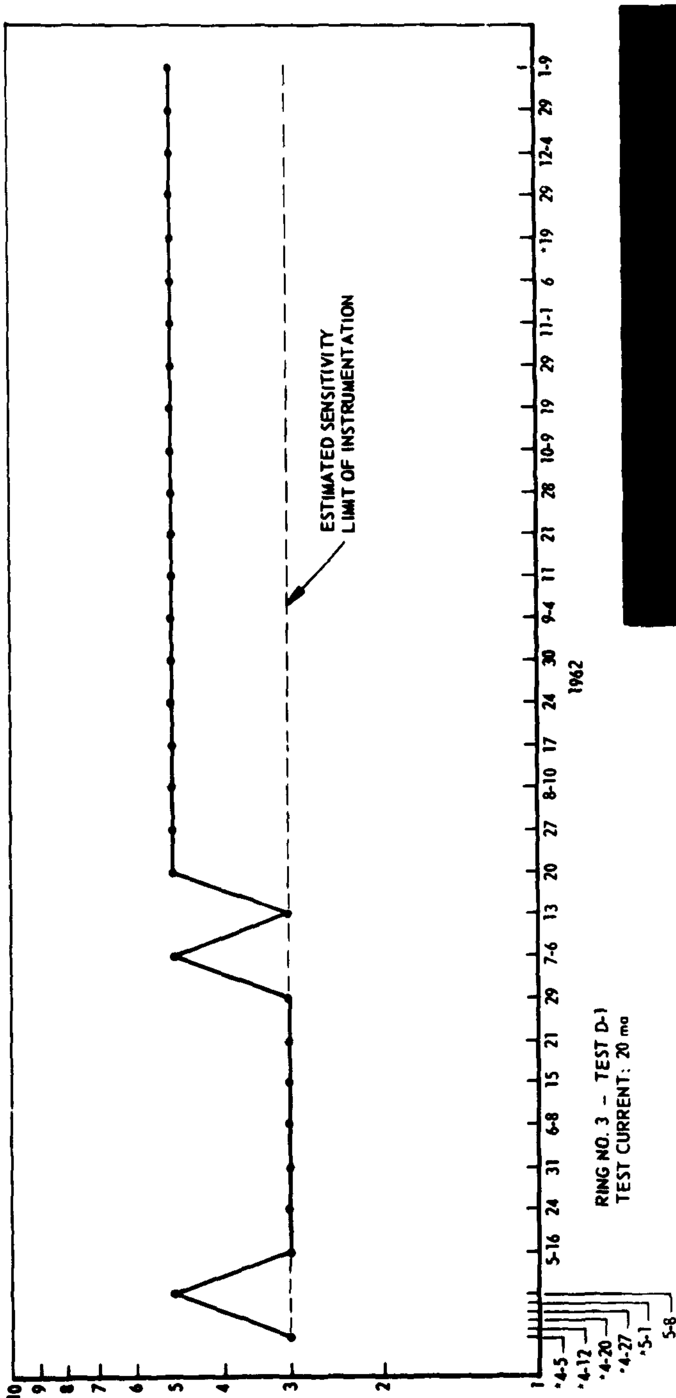


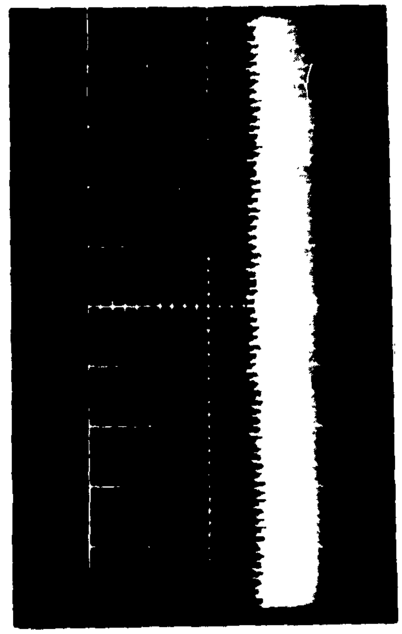
Test current (during this photo): 20 ma
Horizontal sweep speed: 1 cm/sec
Vertical sensitivity: 1 mv/cm
Total test hours: 8500

* BACK DIFFUSION OF OIL TO CHAMBER OCCURRED; CHAMBER SATURATED WITH DOW CORNING 704 OIL VAPOR

UNCLASSIFIED
A311368-A-028

A-2

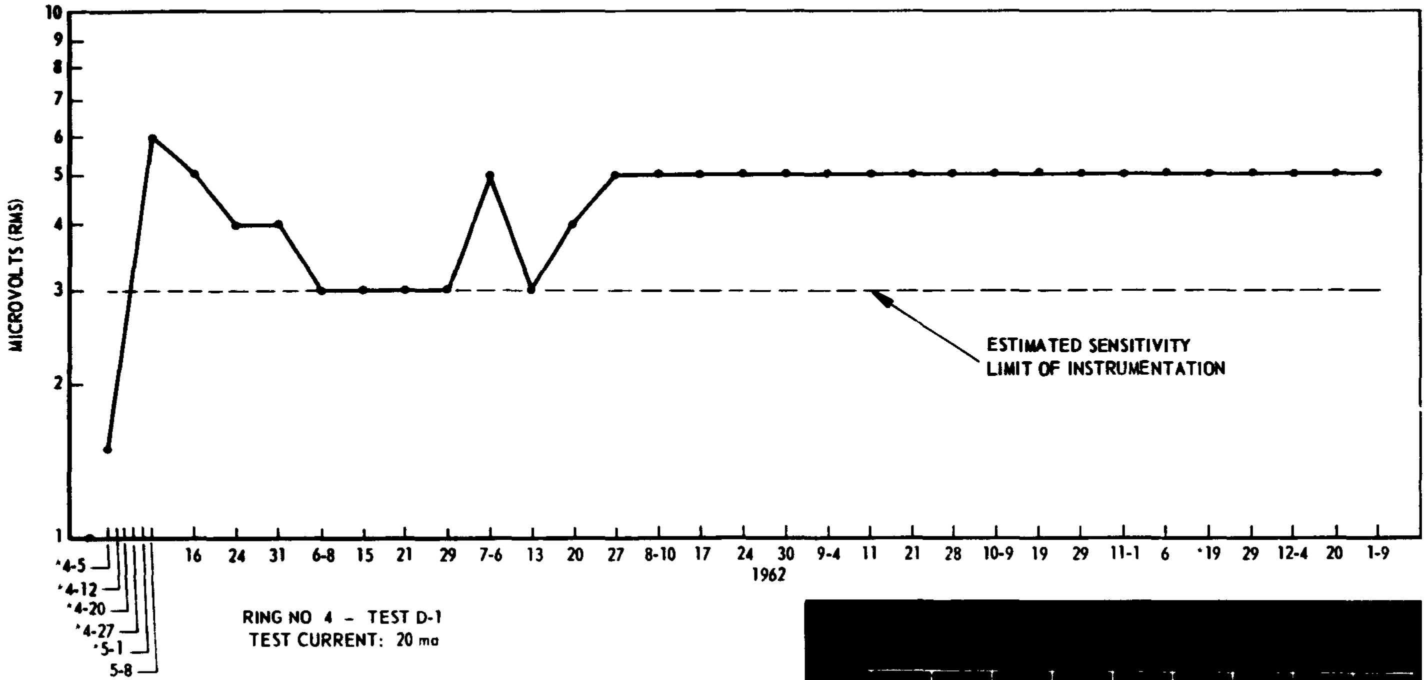


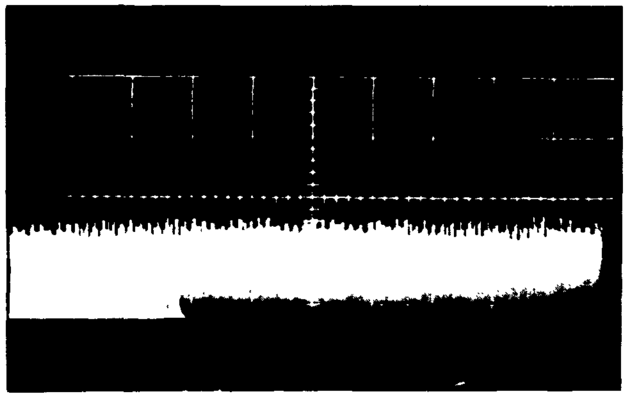


Test current (during this photo): 20 ma
Horizontal sweep speed: 1 cm sec
Vertical sensitivity: 1 mv cm
Total test hours: 8500

* BACK DIFFUSION OF OIL TO CHAMBER OCCURRED; CHAMBER SATURATED WITH DOW CORNING 704 OIL VAPOR

UNCLASSIFIED
A311368-A-027

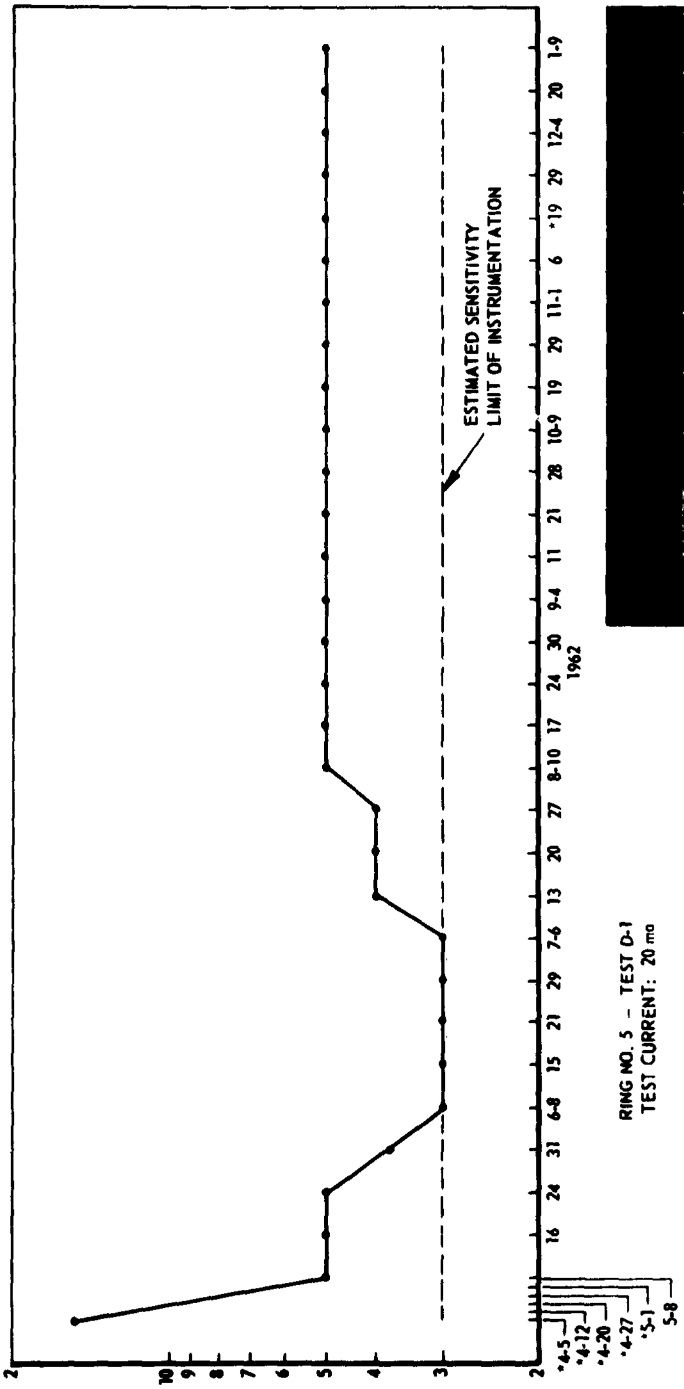




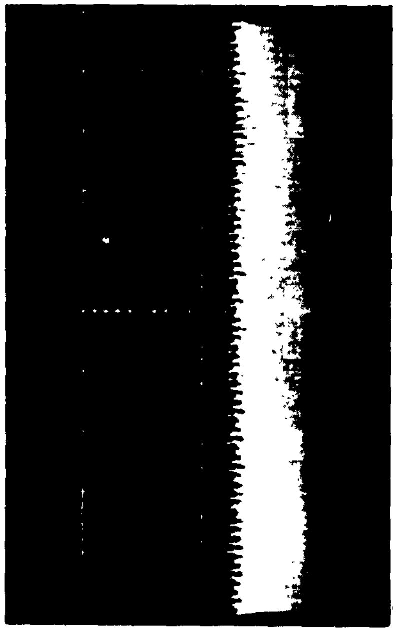
Test current (during this photo). 20 ma
Horizontal sweep speed: 1 cm sec
Vertical sensitivity: 1 mv cm
Total test hours: 8500

* BACK DIFFUSION OF OIL TO CHAMBER OCCURRED; CHAMBER SATURATED WITH DOW CORNING 704 OIL VAPOR

UNCLASSIFIED
A311368-A-004



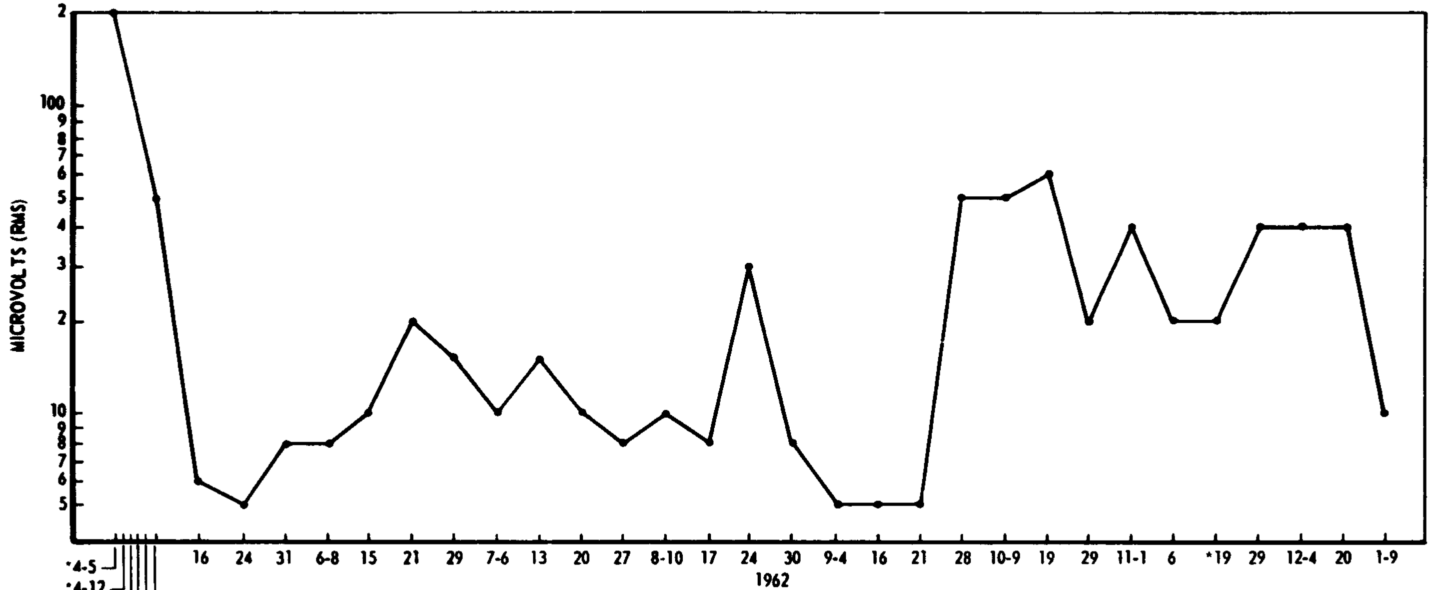
RING NO. 5 – TEST D-1
TEST CURRENT: 20 ma



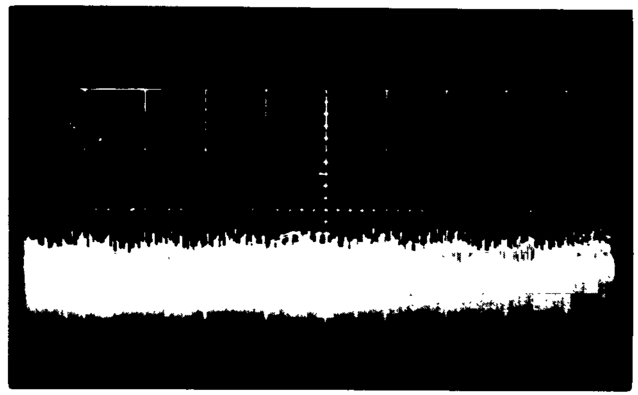
Test current (during this photo): 20 ma
Horizontal sweep speed: 1 cm/sec
Vertical sensitivity: 1 mv/cm
Total test hours: 8500

* BACK DIFFUSION OF OIL TO CHAMBER OCCURRED; CHAMBER SATURATED WITH DOW CORNING 704 OIL VAPOR

UNCLASSIFIED
A311368-A-005



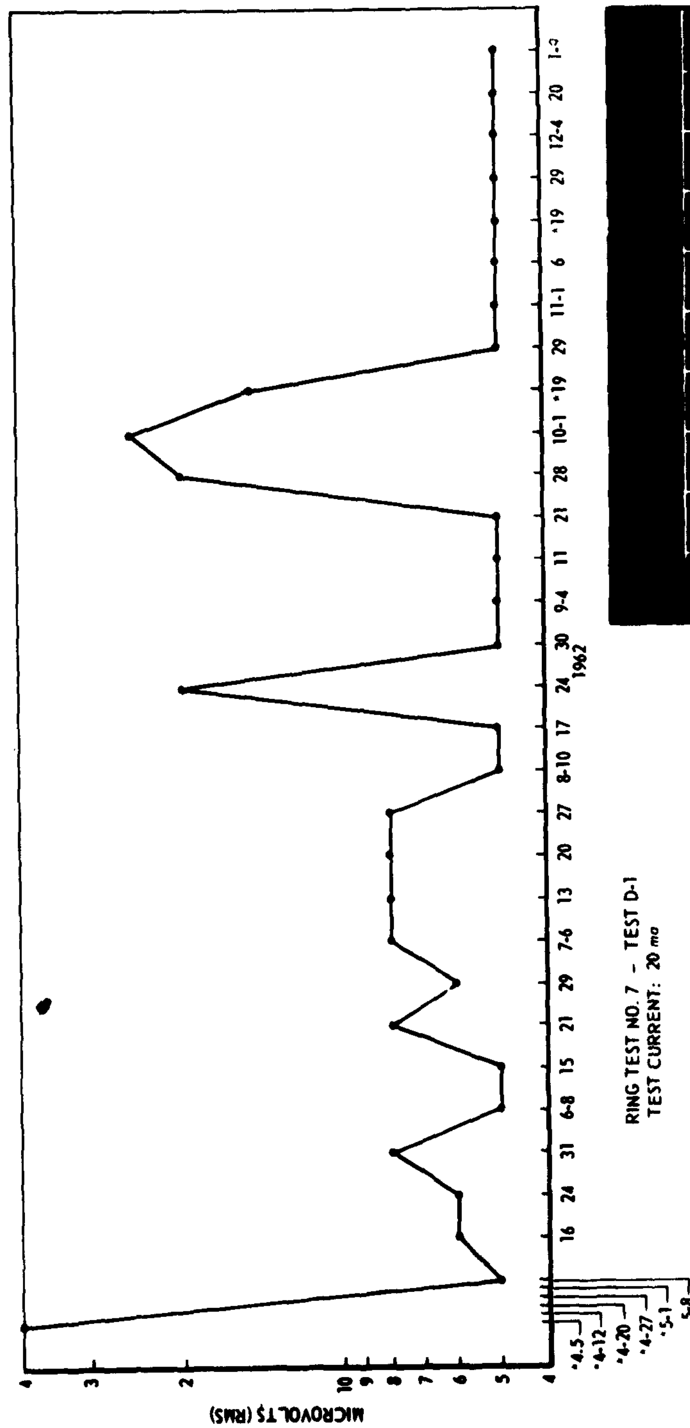
RING NO. 6 – TEST D-1
TEST CURRENT: 20 ma

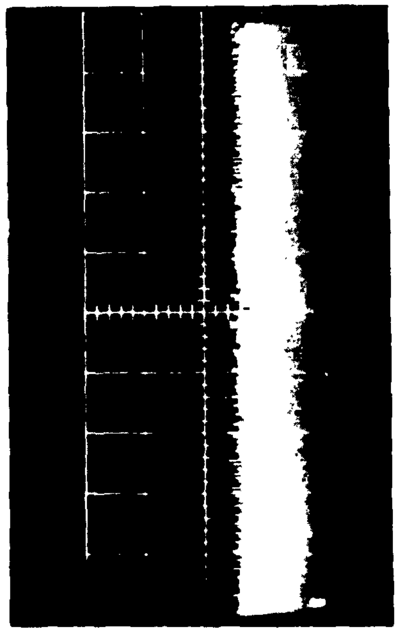


Test current (during this photo): 20 ma
Horizontal sweep speed: 1 cm/sec
Vertical sensitivity: 1 mv/cm
Total test hours: 8500

* BACK DIFFUSION OF OIL TO CHAMBER OCCURRED; CHAMBER SATURATED WITH DOW CORNING 704 OIL VAPOR

UNCLASSIFIED
A311368-A-006



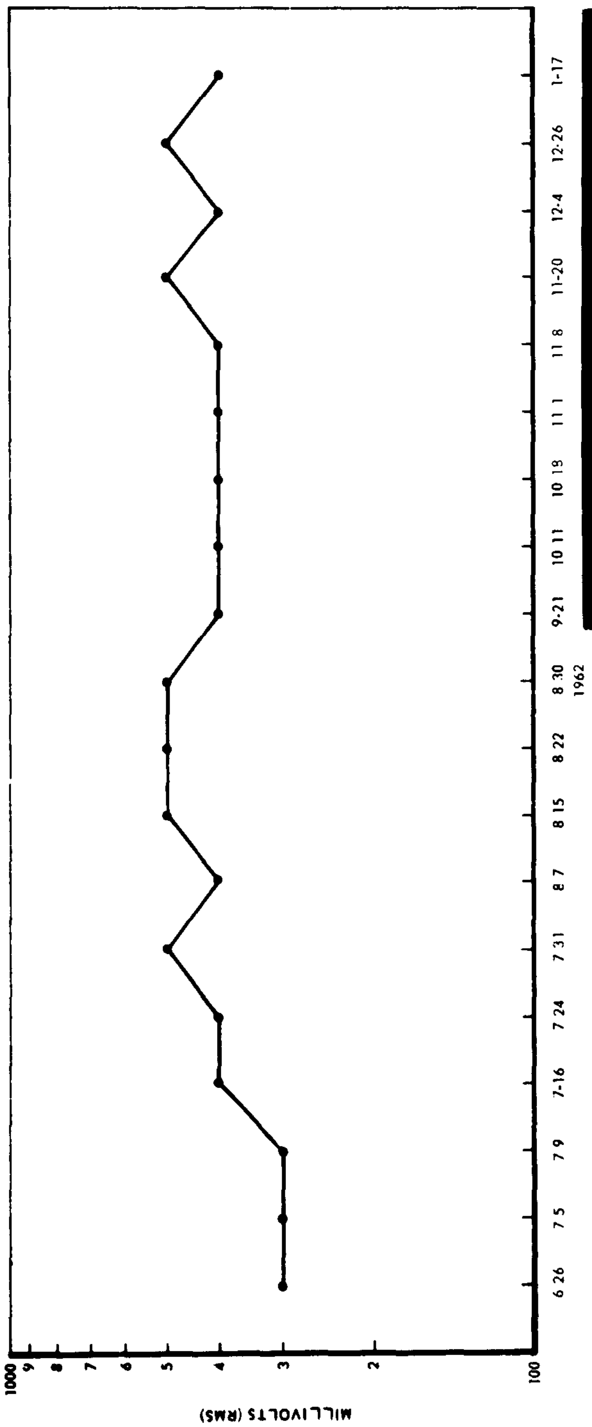


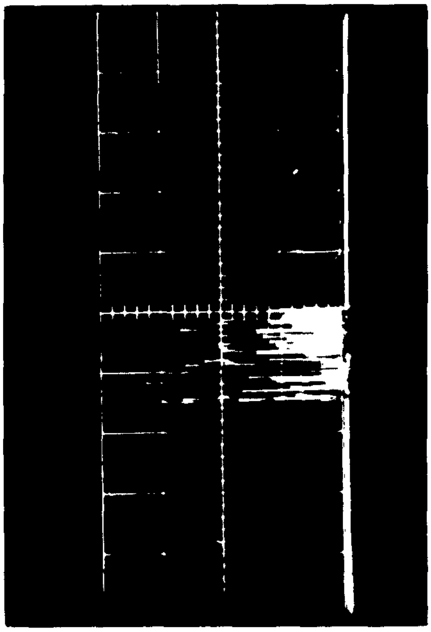
RING TEST NO. 7 - TEST D-1
TEST CURRENT: 20 ma

Test current (during this photo): 20 ma
Horizontal sweep speed: 1 cm sec
Vertical sensitivity: 1 mv cm
Total test hours: 8500

* BACK DIFFUSION OF OIL TO CHAMBER OCCURRED; CHAMBER SATURATED WITH DOW CORNING 704 OIL VAPOR

UNCLASSIFIED
A311368-A-007

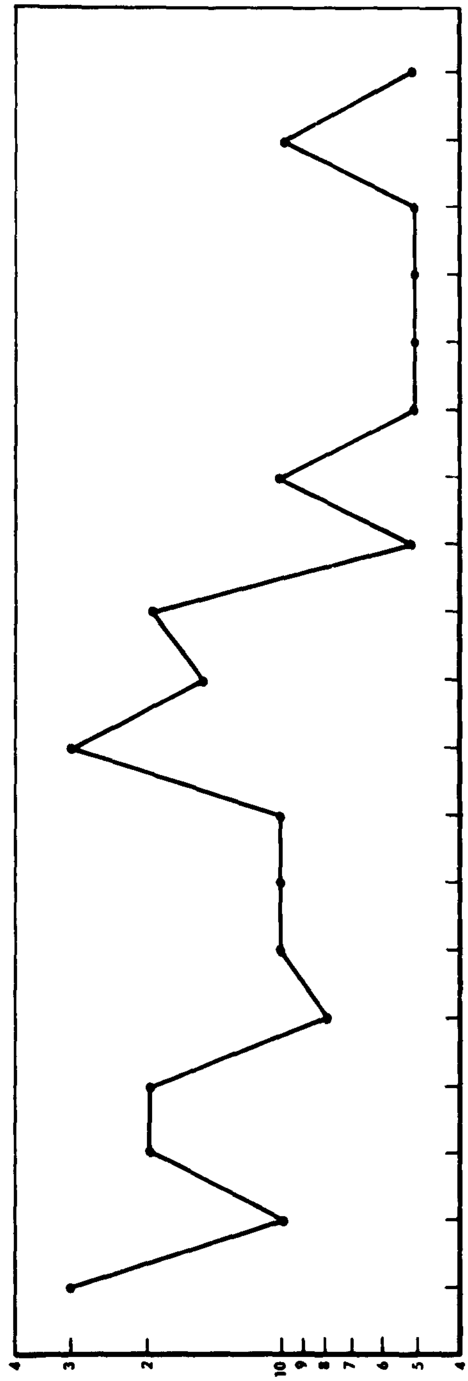


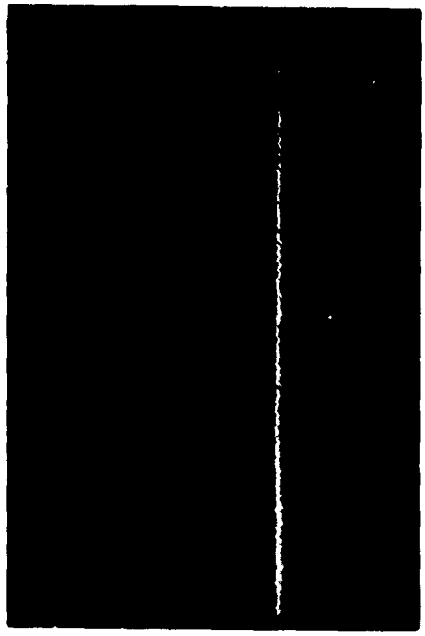


RING NO 1 -- TEST F-1
TEST CURRENT 5 ma

Test current during this photo: 5 ma
Horizontal sweep speed: 1 cm sec
Vertical sensitivity 25 mv cm
Total test hours 5000

UNCLASSIFIED
A311368-A-008

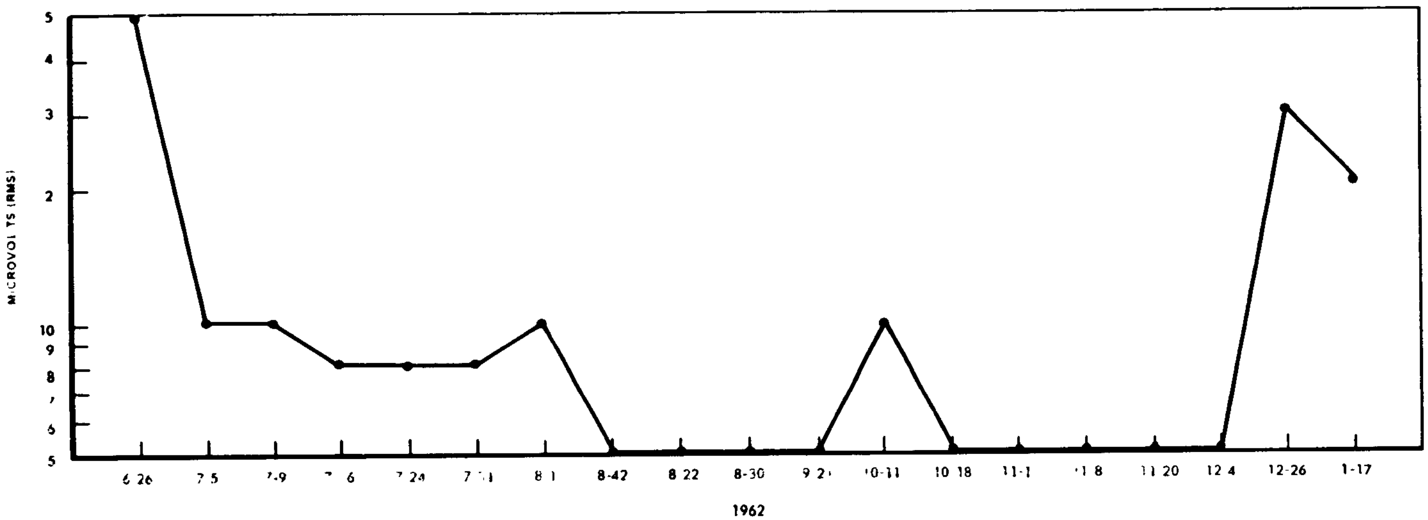




RING NO. 2 – TEST E 1
TEST CURRENT: 5 ma

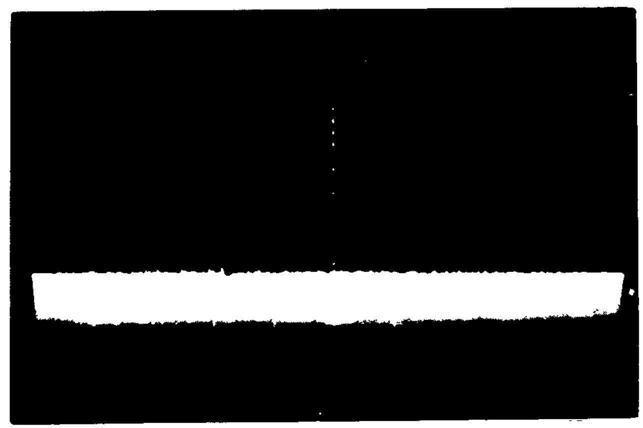
Test current (during this photo) 5 ma
Horizontal sweep speed: 1 cm sec
Vertical sensitivity: 0.1 mv cm
Total test hours: 5000

UNCLASSIFIED
A311368-A-009



RING NO 3 -- TEST E 1

TEST CURRENT 5 ma



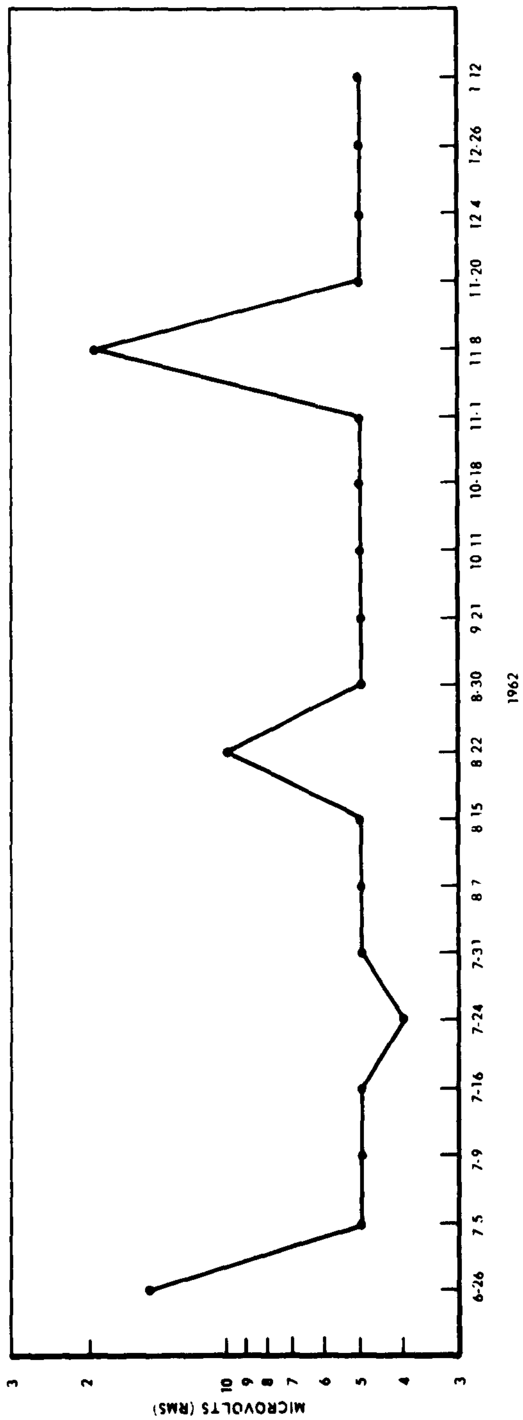
Test current (during this photo) 5 ma

Horizontal sweep speed; 1 cm sec

Vertical sensitivity, 0 1 mv cm

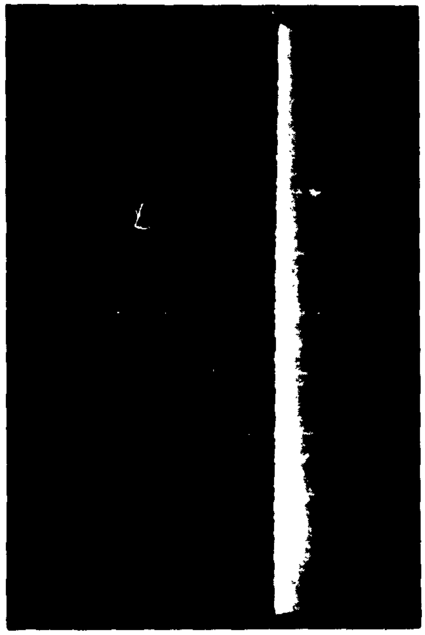
Total test hours 5000

UNCLASSIFIED
A311368-A 010



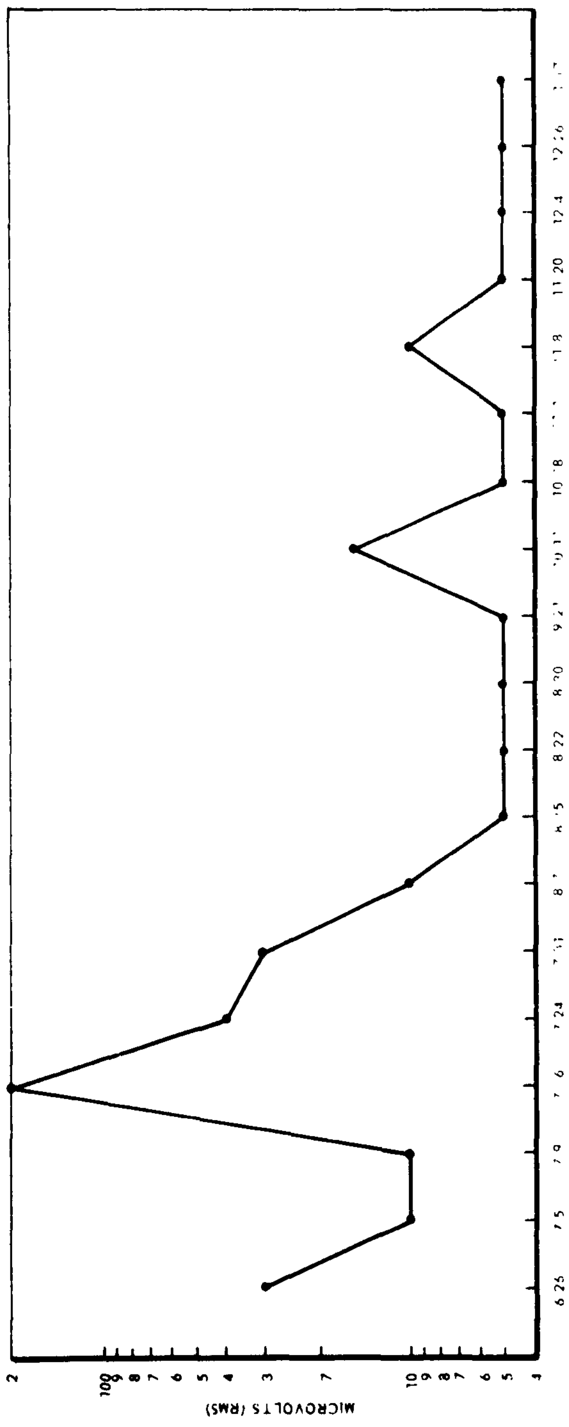
RING NO. 4 – TEST E-1

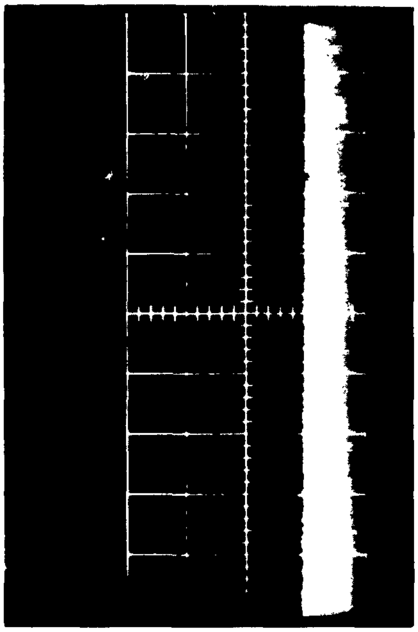
TEST CURRENT 5 ma

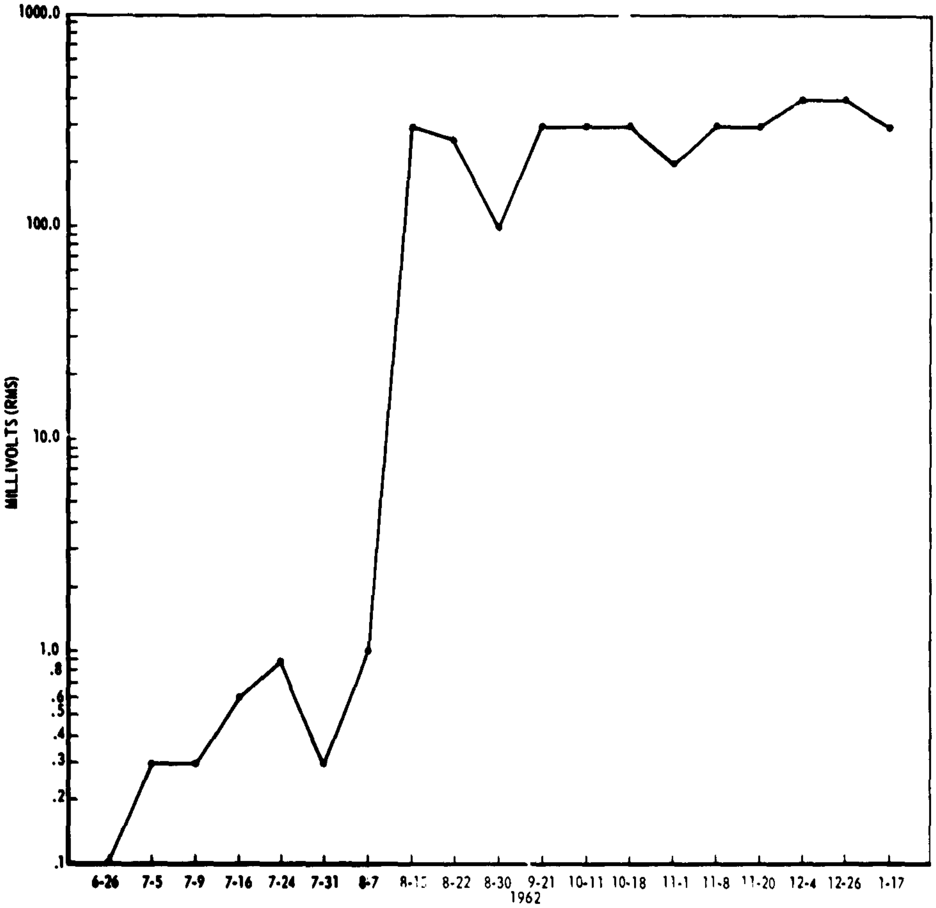


Test current during this photo: 5 ma
Horizontal sweep speed 1 cm/sec
Vertical sensitivity 0.1 mv/cm
Total test hours 5000

UNCLASSIFIED
A311368-A 011

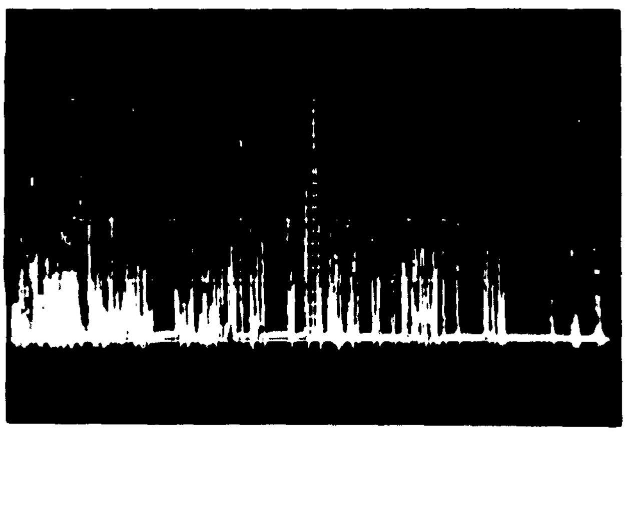

MICROVOLTS (RMS)
1962
RING NO 5 - TEST E 1



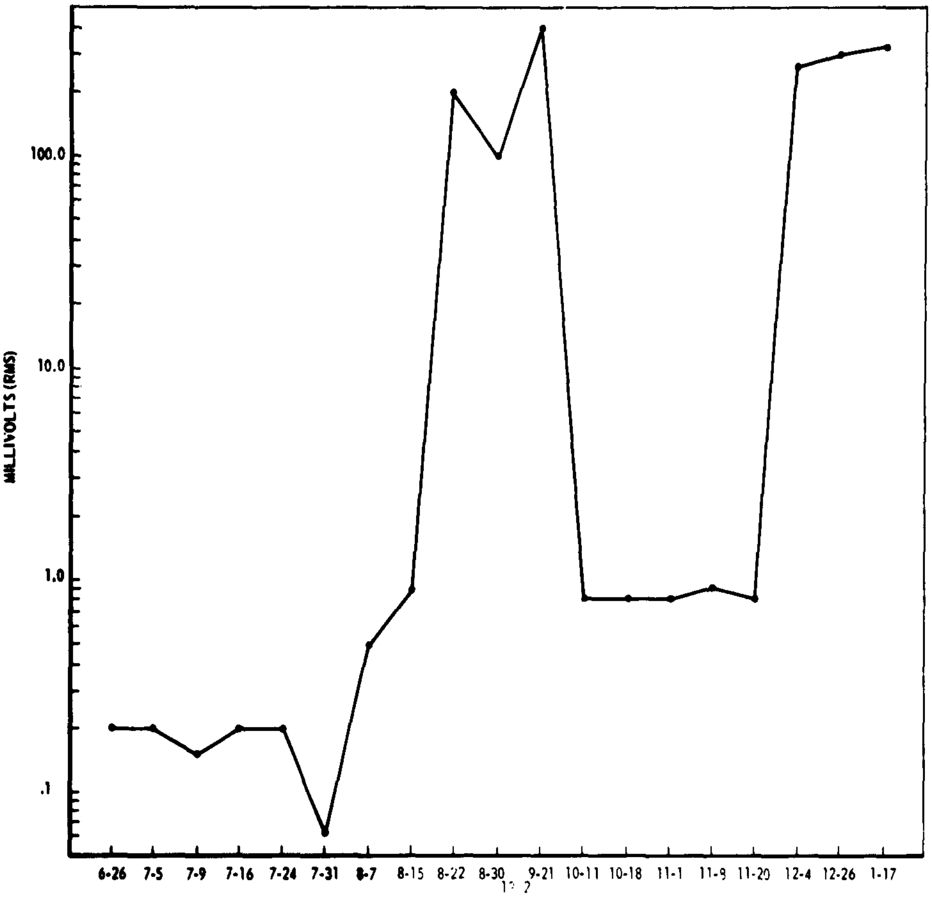


RING NO. 6 – TEST E-1
TEST CURRENT: 5 ma

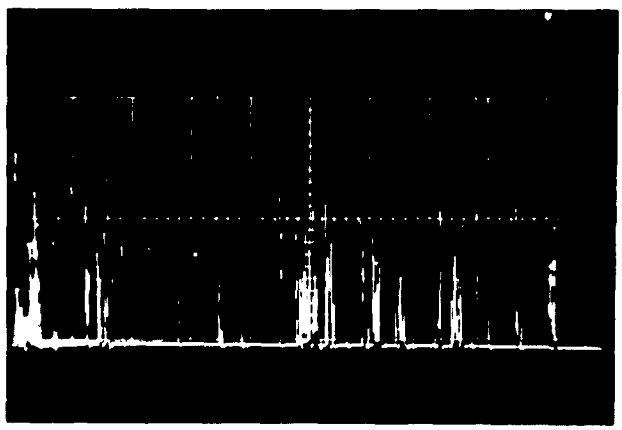
Test current (during this photo): 5 ma
Horizontal sweep speed: 1 cm/sec
Vertical sensitivity: 25 mv/cm
Total test hours: 5000



UNCLASSIFIED

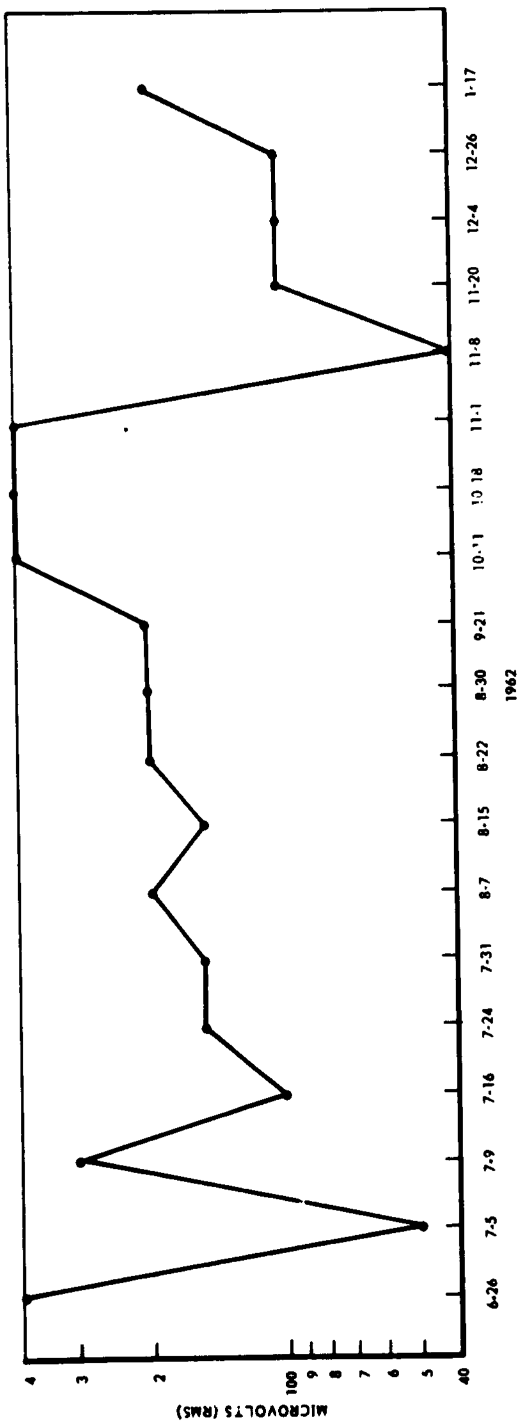


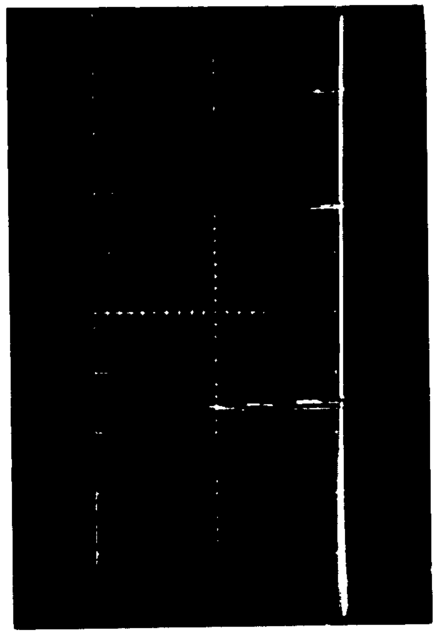
RING NO. 7 – TEST E-1
TEST CURRENT: 5 ma



Test current (during this photo): 5 ma
Horizontal sweep speed: 1 cm/sec
Vertical sensitivity: 25 mv/cm
Total test hours: 5000

UNCLASSIFIED
A311368-A-014



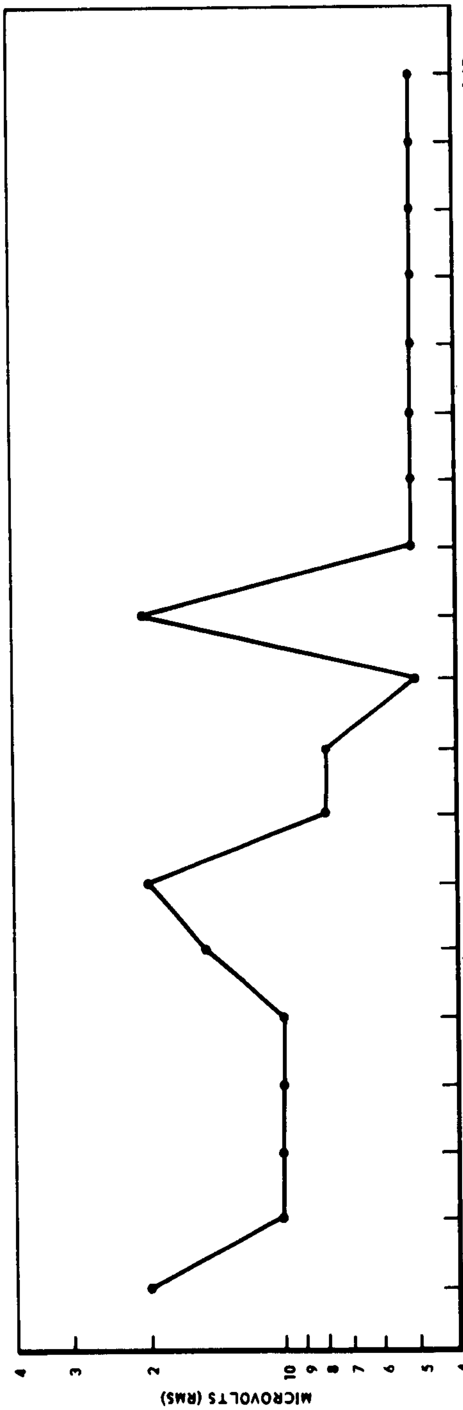


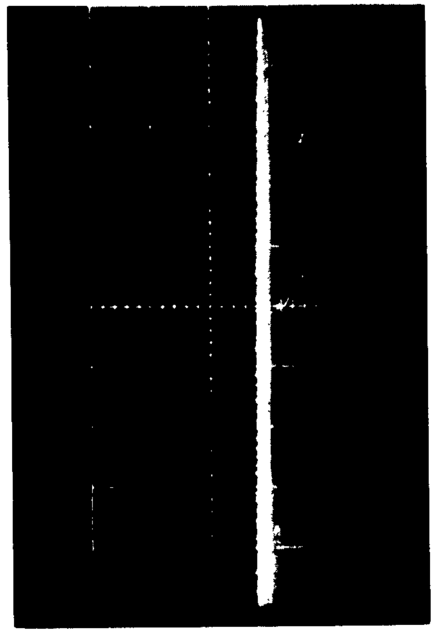
RING NO. 8 – TEST E-1

TEST CURRENT 5 ma

Test current (during this photo) 5 ma
Horizontal sweep speed 1 cm sec
Vertical sensitivity 25 mv cm
Total test hours 5000

UNCLASSIFIED
A311368-A-015



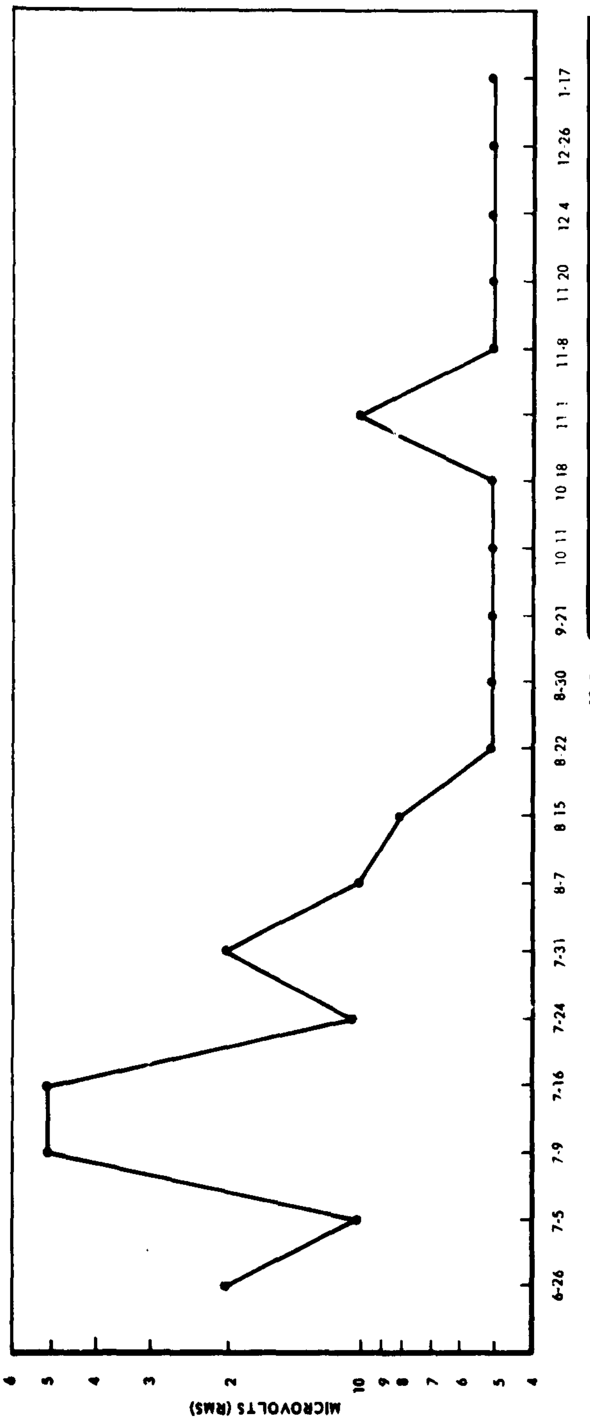


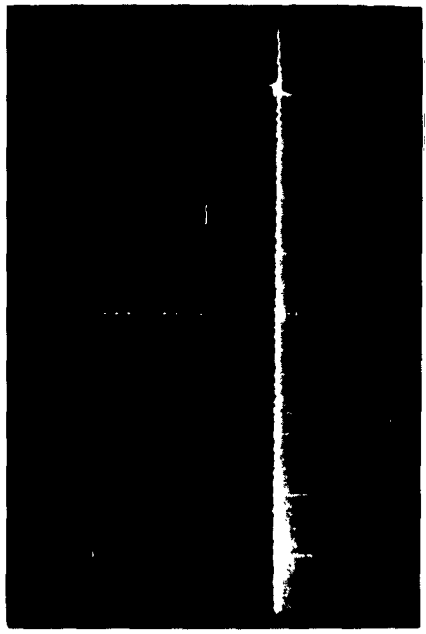
RING NO. 9 – TEST E-1

TEST CURRENT- 5 ma

Test current (during this photo) 5 ma
Horizontal sweep speed 1 cm sec
Vertical sensitivity: 0.1 mv cm
Total test hours: 5000

UNCLASSIFIED
A311368-A-016



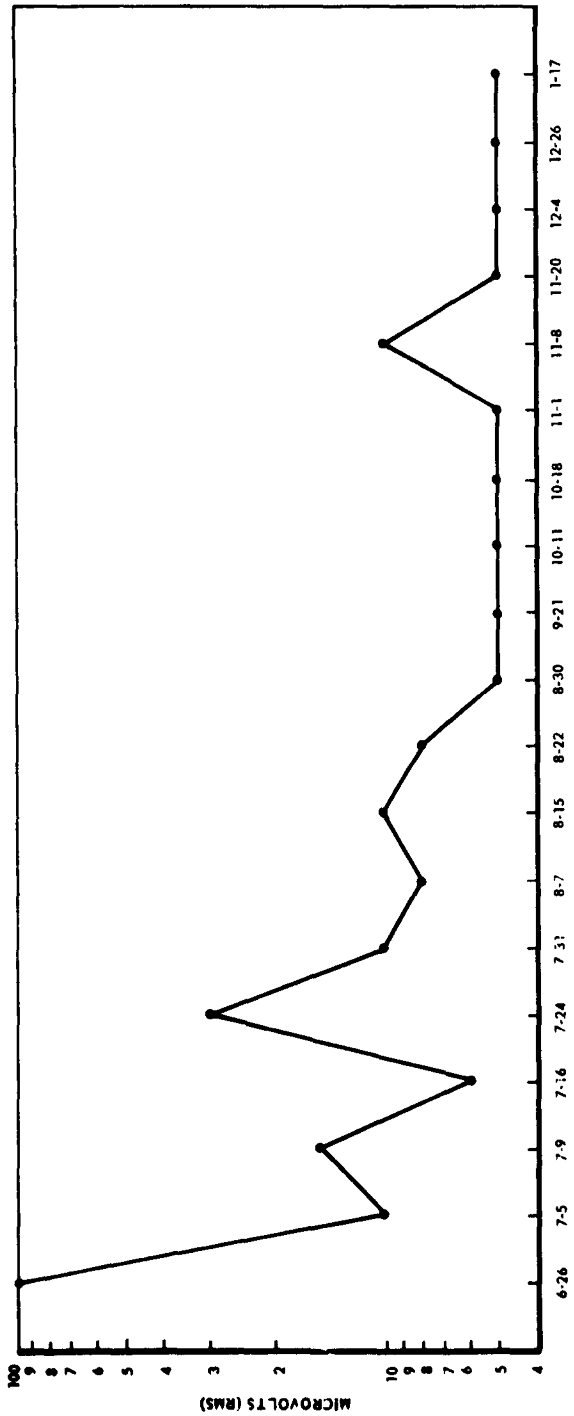


RING NO 10 – Test E-1

TEST CURRENT: 5 ma

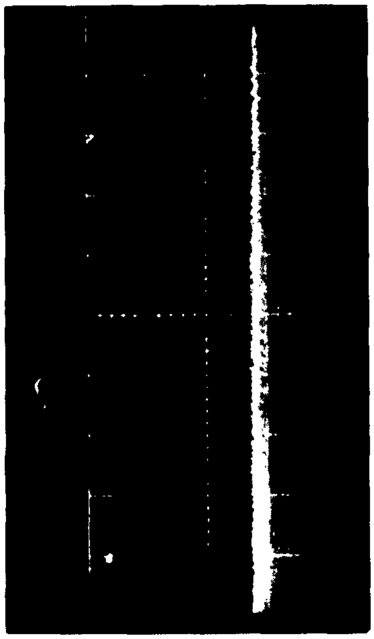
Test current (during this photo) 5 ma
Horizontal sweep speed: 1 cm sec
Vertical sensitivity: 0.1 mv cm
Total test hours. 5000

UNCLASSIFIED
A311368-A-017



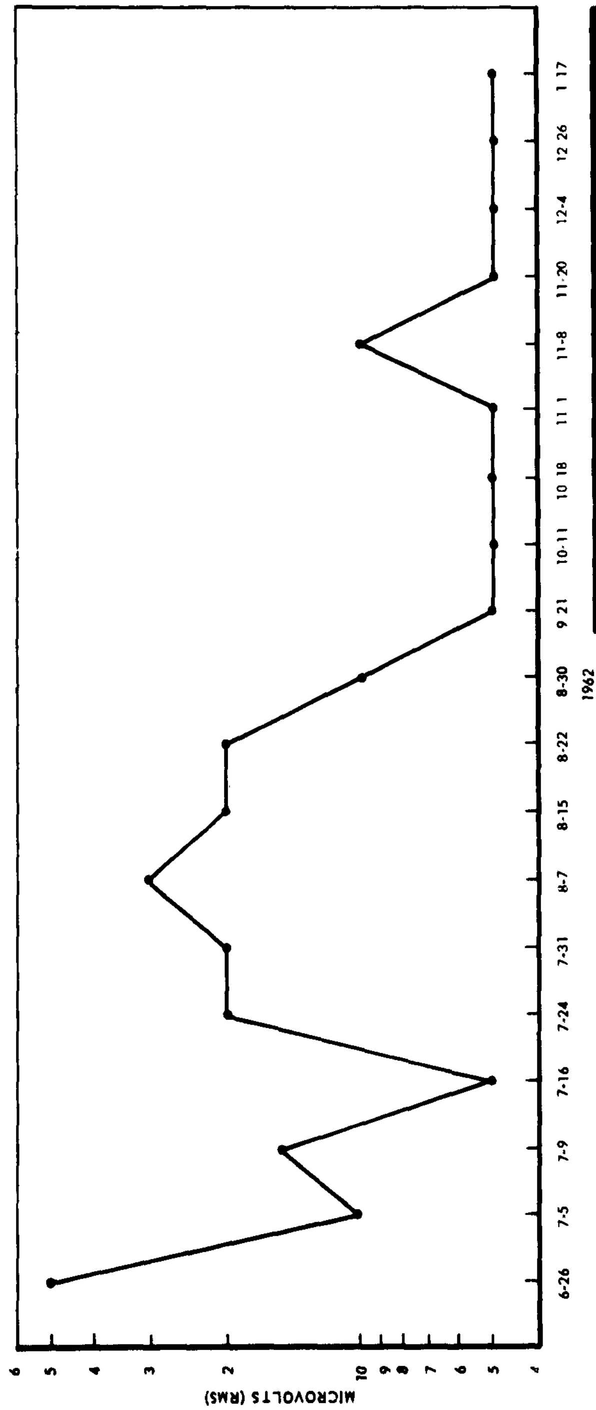
RING NO. 11 – TEST E-1

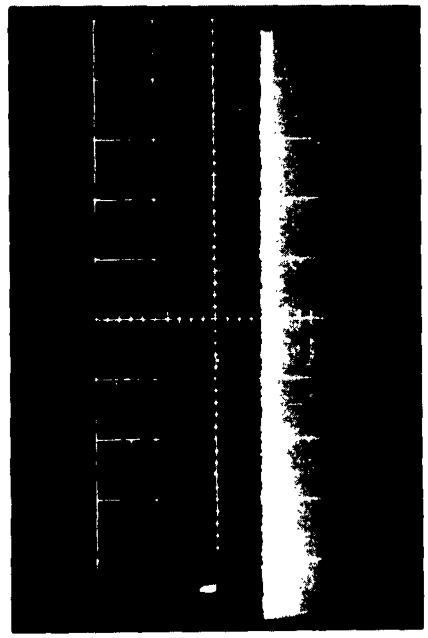
TEST CURRENT, 5 ma



Test current (during this photo): 5 ma
Horizontal sweep speed: 1 cm sec
Vertical sensitivity, 0-1 mv/cm
Total test hours 5000

UNCLASSIFIED
A311368-A-018



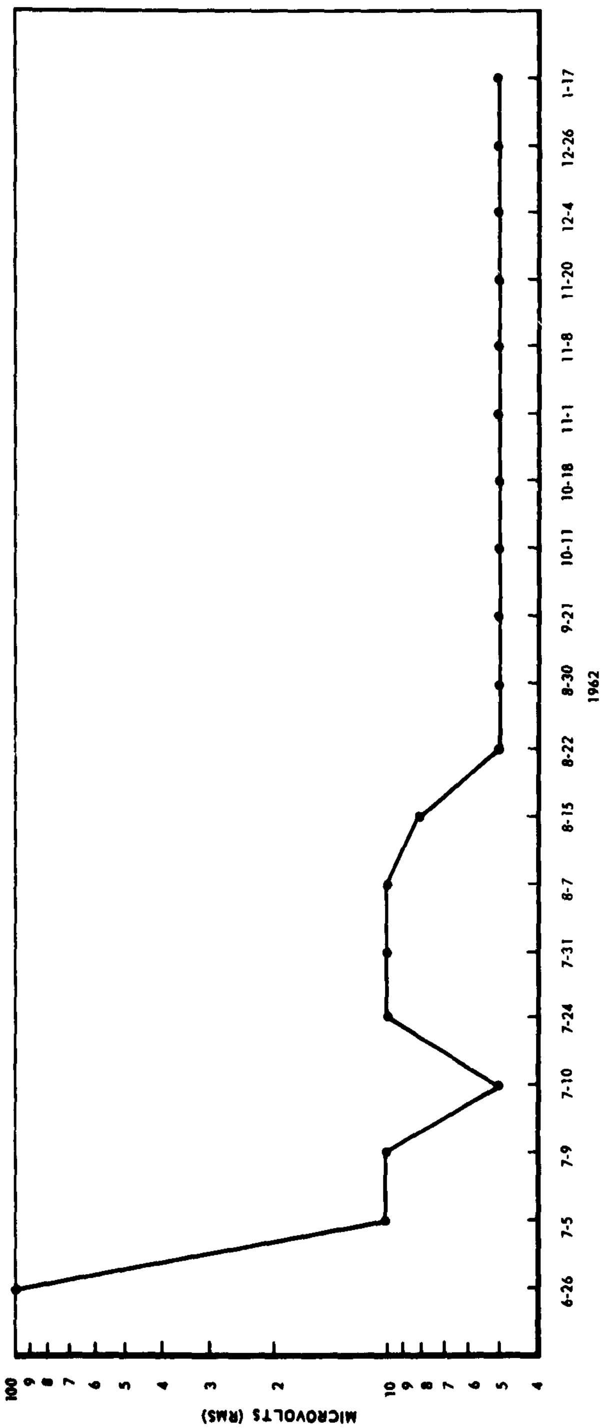


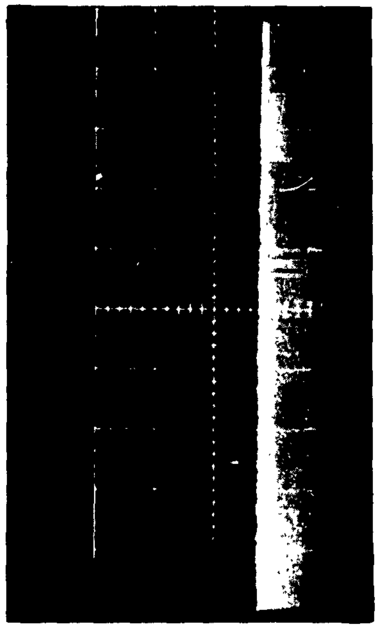
RING TEST NO. 12 — TEST E-1

TEST CURRENT. 5 ma

Test current (during this photo): 5 ma
Horizontal sweep speed: 1 cm sec
Vertical sensitivity: 0.1 mv cm
Total test hours: 5000

UNCLASSIFIED
A311368-A-019



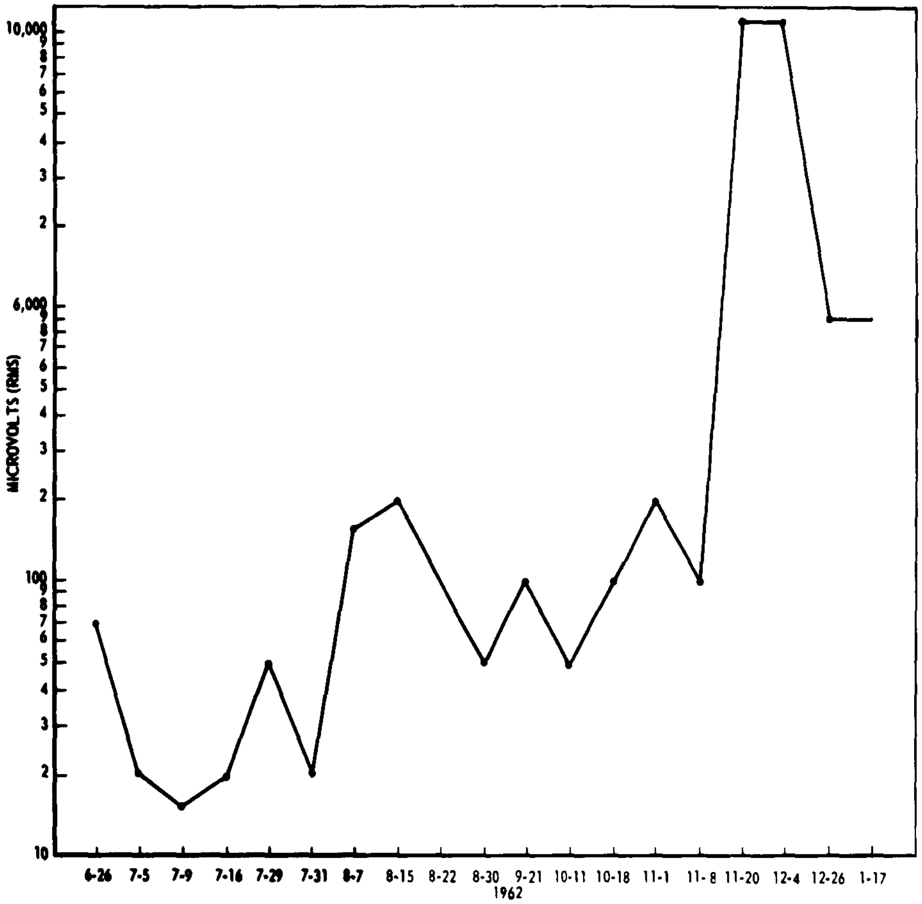


RING NO. 13 – TEST E-1

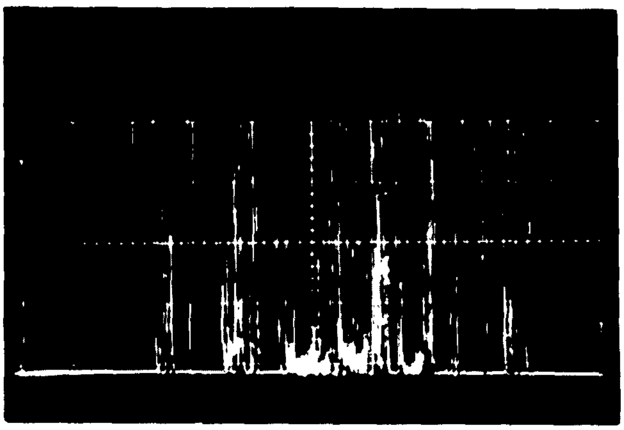
TEST CURRENT: 5 ma

Test current (during this photo): 5 ma
Horizontal sweep speed: 1 cm sec
Vertical sensitivity: 0.1 mv cm
Total test hours: 5000

UNCLASSIFIED
A311368-A-020

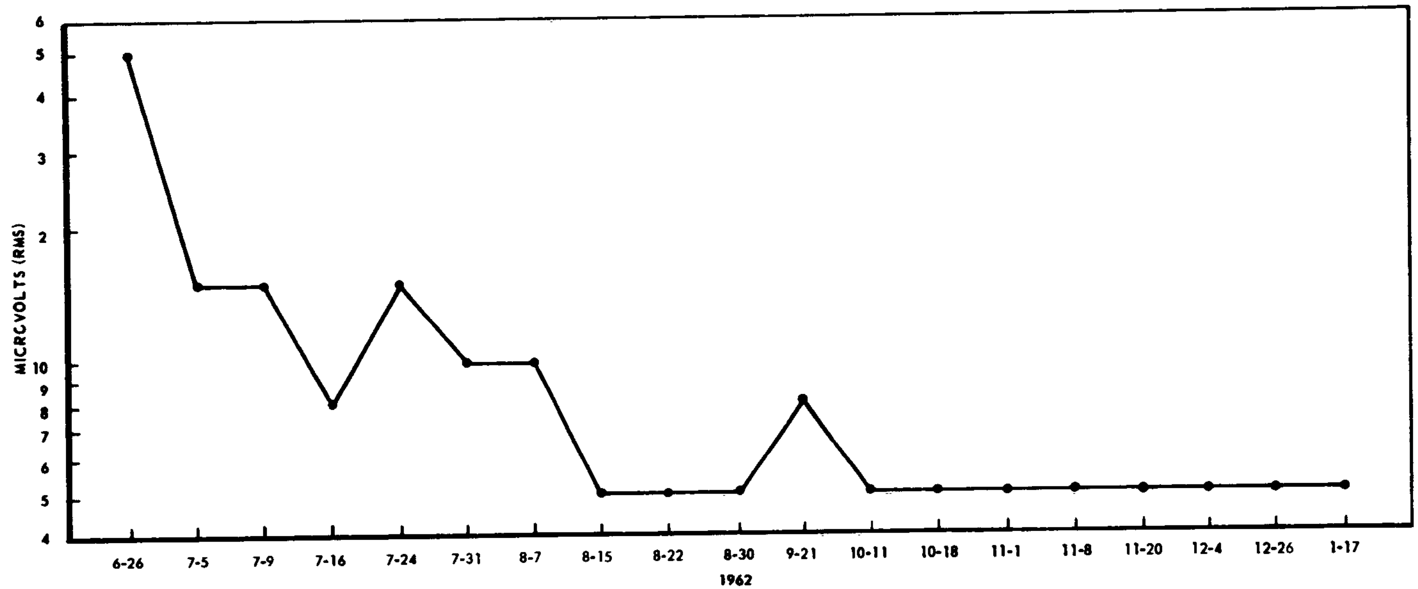


RING NO. 14 - TEST E-1
TEST CURRENT: 5 ma



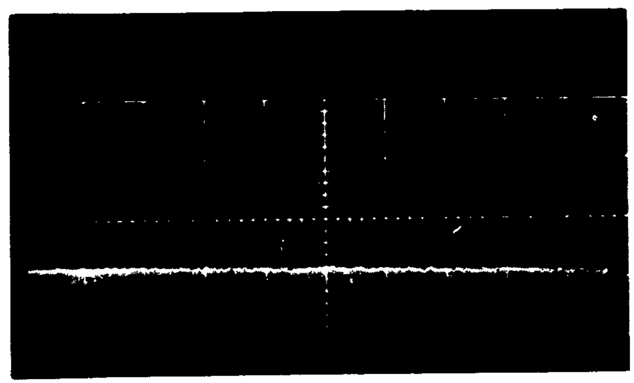
Test current (during this photo): 5 ma
Horizontal sweep speed: 1 cm/sec
Vertical sensitivity: 25 mv/cm
Total test hours: 5000

UNCLASSIFIED
A311368-A-621



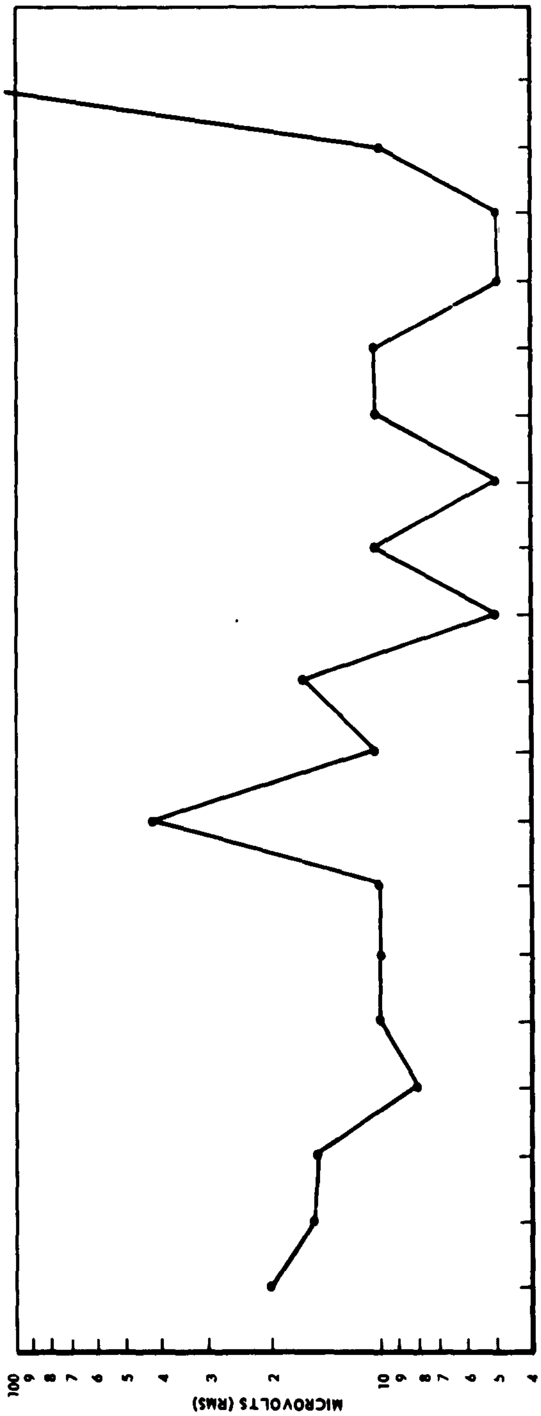
RING NO. 15 – TEST E-1

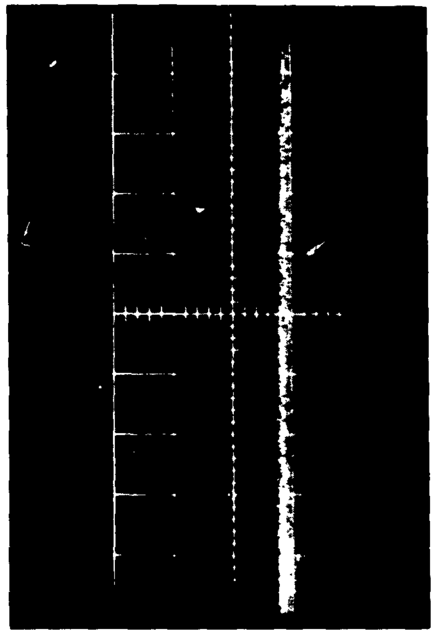
TEST CURRENT: 5 ma



Test current (during this photo). 5 ma
Horizontal sweep speed. 1 cm, sec
Vertical sensitivity: 0.1 mv cm
Total test hours: 5000

UNCLASSIFIED
A311368-A-022

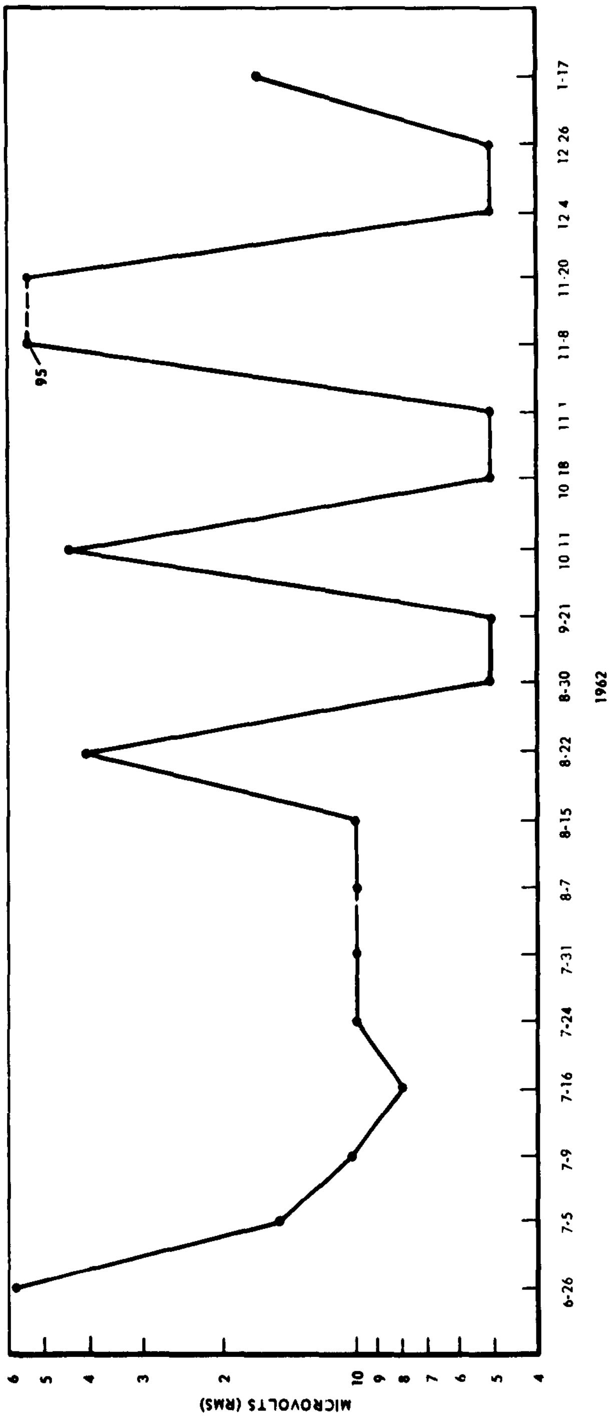




RING NO 16 – TEST E-1
TEST CURRENT: 5 ma

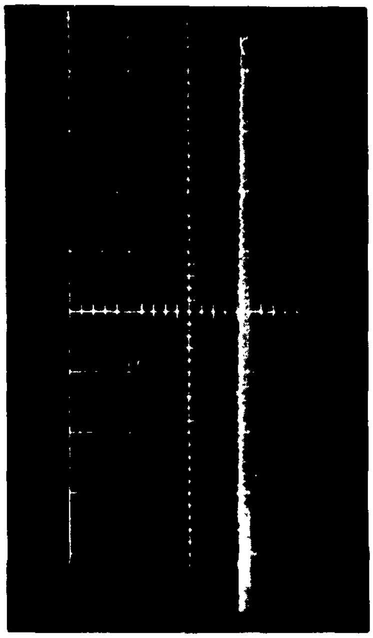
Test current (during this photo): 5 ma
Horizontal sweep speed: 1 cm sec
Vertical sensitivity: 0.1 mv cm
Total test hours: 5000

UNCLASSIFIED
A311368-A-023



RING NO. 17 – TEST E-1

TEST CURRENT: 5 ma



Test current (during this photo): 5 ma
Horizontal sweep speed. 1 cm sec
Vertical sensitivity 0.1 mv cm
Total test hours 5000

UNCLASSIFIED
A311368-A-024

DISTRIBUTION

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Defense Documentation Center Arlington Hall Station Arlington 12, Virginia	10
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	111

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